# Biomechanics of transfemoral amputees fitted with osseointegrated fixation: Loading data for evidence-based practice

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**Abstract of presentation as Guest speaker: Frossard L, Brånemark R. Biomechanics of transfemoral amputees fitted with osseointegrated fixation: Loading data for evidence-based practice. 2010. III international conference on Advances in Orthopaedic Osseointegration. Gothenburg, Sweden. p 120**

This presentation will provide an overview of the load applied on the residuum of transfemoral amputees fitted with an osseointegrated fixation during (A) rehabilitation, including static and dynamic load bearing exercises (e.g., rowing, adduction, abduction, squat, cycling, walking with aids) [1-10], and (B) activities of daily living including standardized activities (e.g., level walking in straight line and around a circle, ascending and descending slopes and stairs)[11-13] and activities in real world environments [14-17].

A particular emphasis will be placed on the outcomes of several studies for an evidence-based design of the rehabilitation program and components of the fixation (e.g., implant, abutment)[6-7, 9, 16, 18-23].

It is anticipated that this work might contribute to the current effort aiming at shortening the rehabilitation program and reducing the incidence of replacement of abutments [23-26].

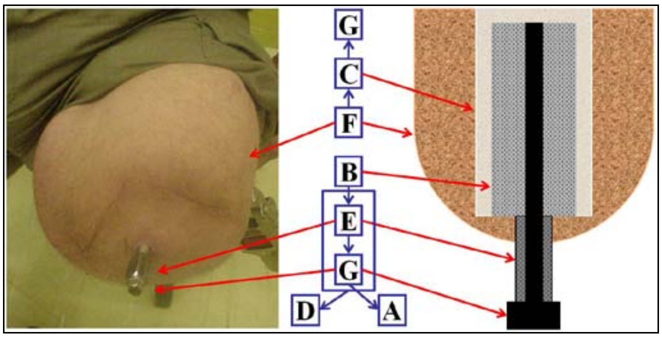



**Figure 1.** Overview of Osseointegrated Prosthesis for Rehabilitation of Amputees (OPRA) relying on a fixation (A) including an implant (B) inserted into the femur (C) as well as an attachment unit (D) made of an abutment (E) penetrating the skin (F) of the residuum (G) and a retaining bolt (G).

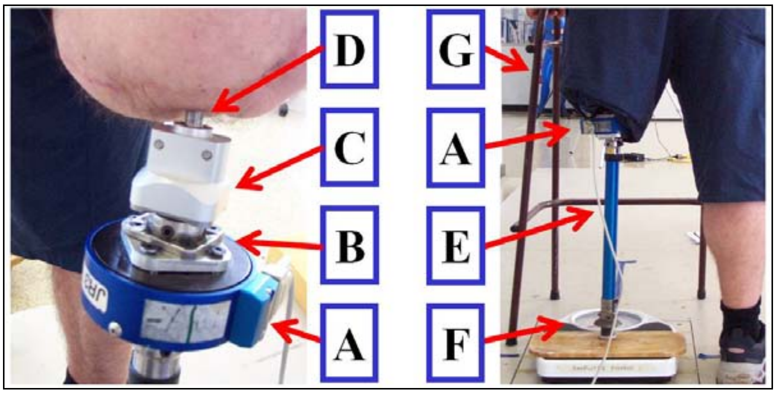
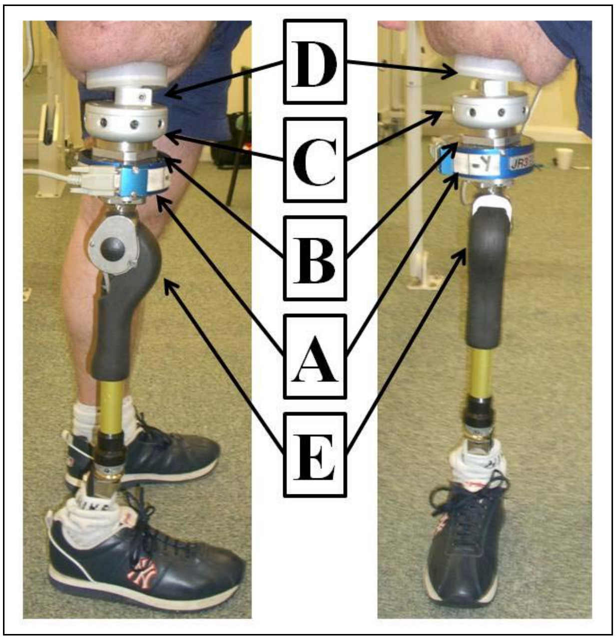



**Figure 2.** Measurement of loading including a six-channel transducer (A) mounted between plates (B) connected to an adaptor (C) and the abutment of the osseointegrated fixation (D), and a long pylon (E), a frame (G), and a weighing scale (F).

**Figure 3.** Side (left) and front (right) views of the prosthetic limb including a multi-axial transducer (A) mounted to designed adaptors (B) that were positioned between the Rotasafe (C) and the abutment (D), and the knee mechanism (E).

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# Biomechanics of transfemoral amputees fitted with osseointegrated fixation: Loading data for evidence-based practice


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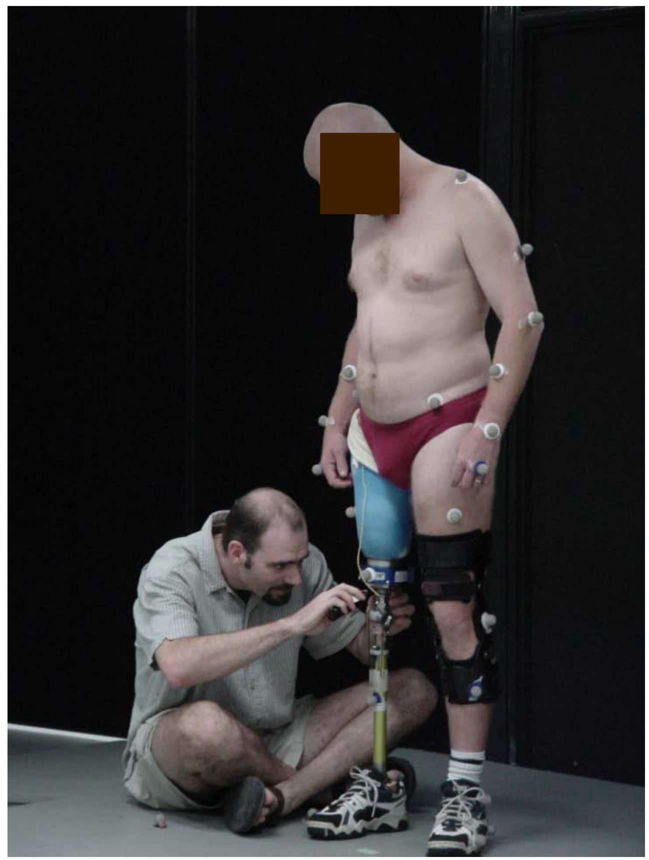
02/09/2010 - Göteborg, Sweden

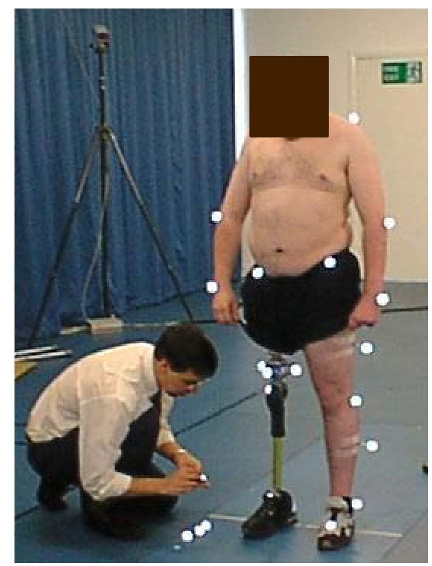
# Overview

**Focus**

**Socket**



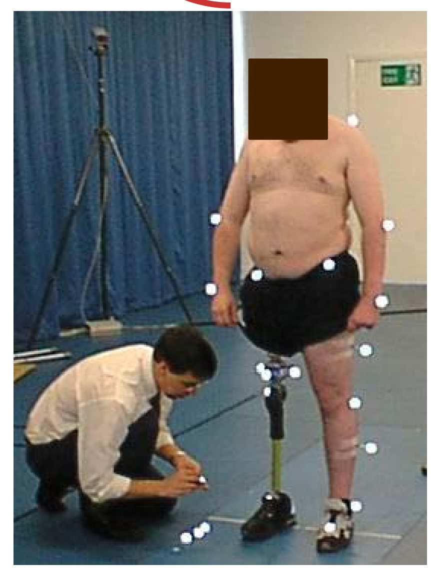
**Fixation**



# Overview

Focus

Fixation



# Overview

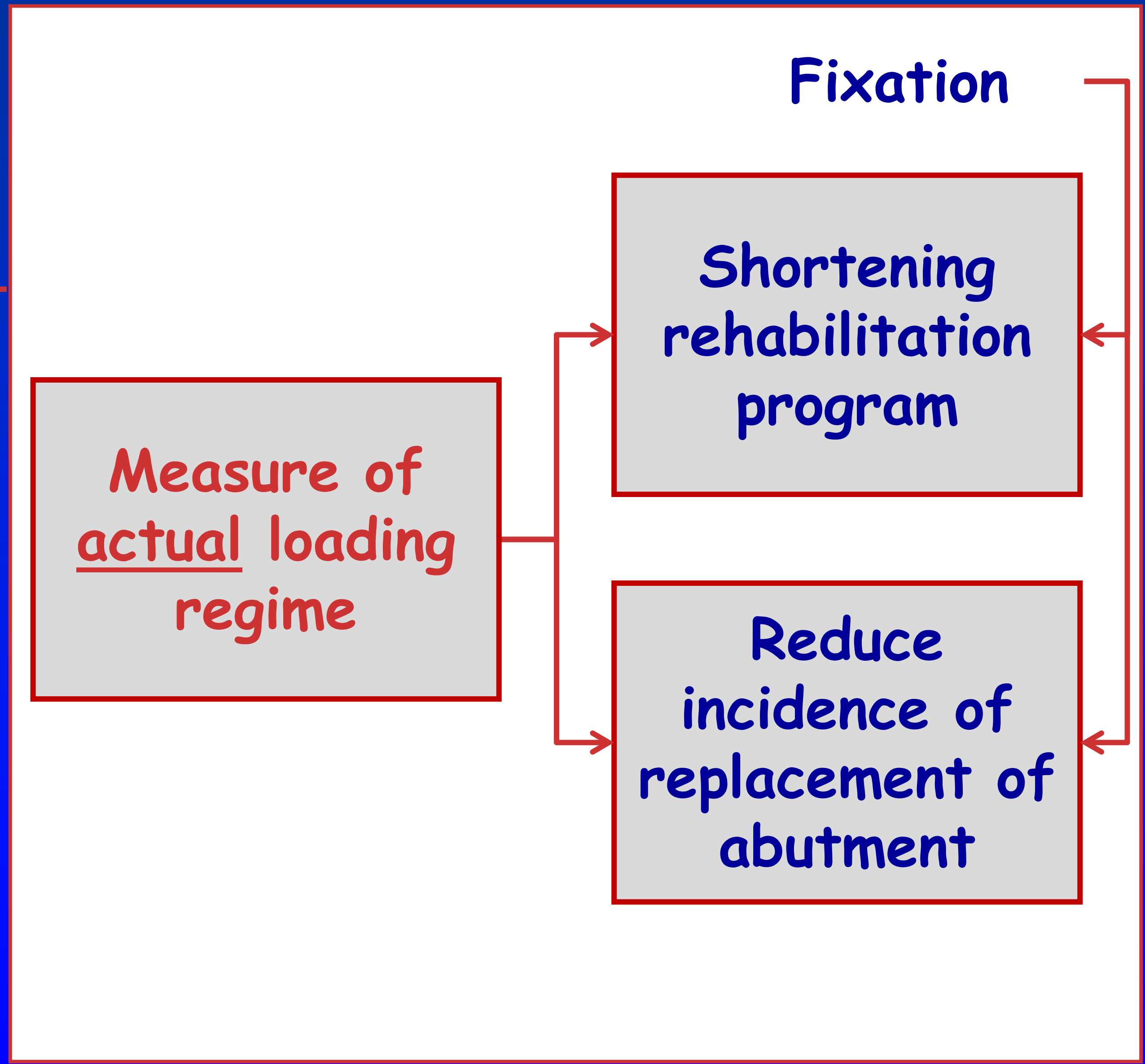
Focus

Fixation

# Overview

Focus

Scope



# Overview

Focus

Scope

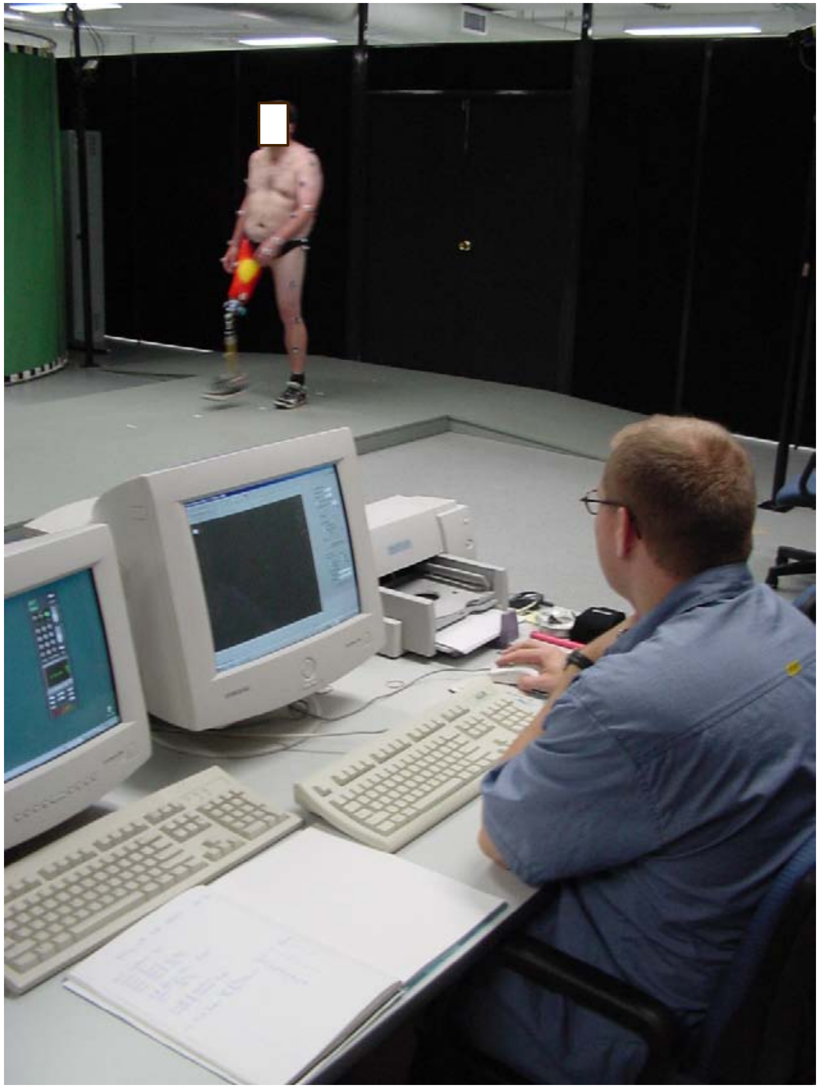
**Publications**

| | |
|---|---|
| Number of publications: | 42 |
| – Published articles: | 11 |
| – Published abstracts: | 28 |
| Industrial reports: | 40 |

Overview

# Tools

Gait lab



# Tools

Gait lab

**Direct measurement**


Frossard *et al*. Development and preliminary testing of a device for the direct measurement of forces and moments in the prosthetic limb of transfemoral amputees during activities of daily living. 2003. Journal of Prosthetics and Orthotics. 15 (4). p 135-142

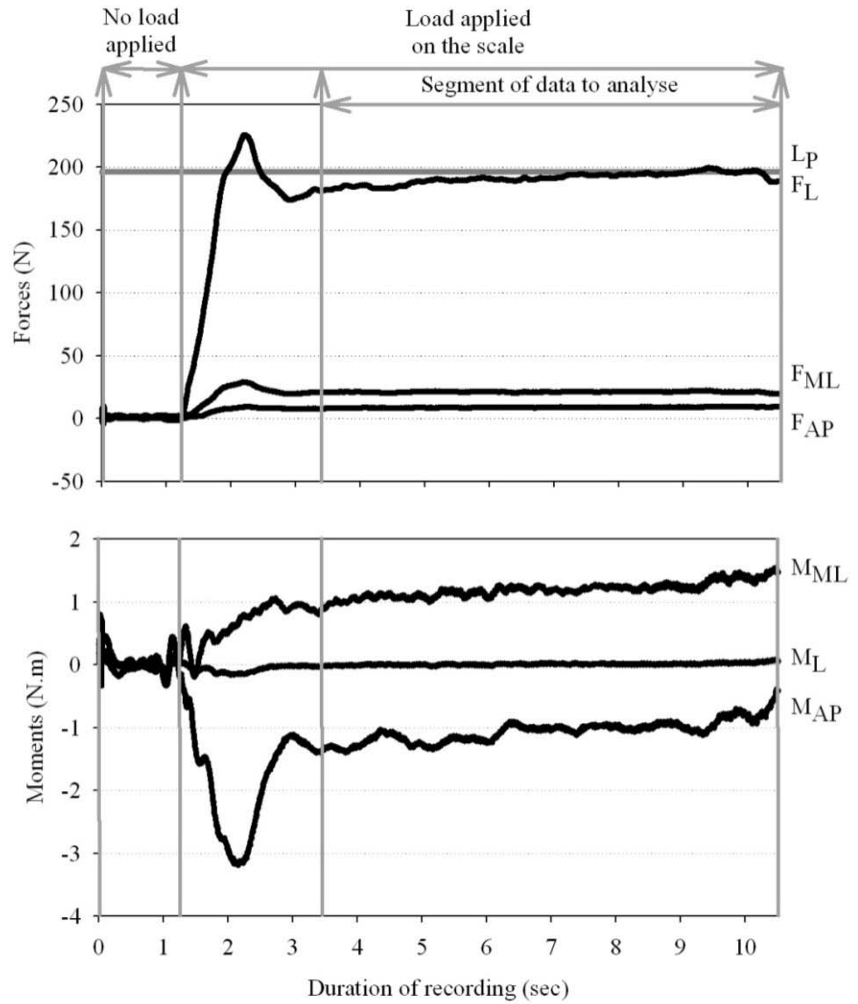
# Measure and results

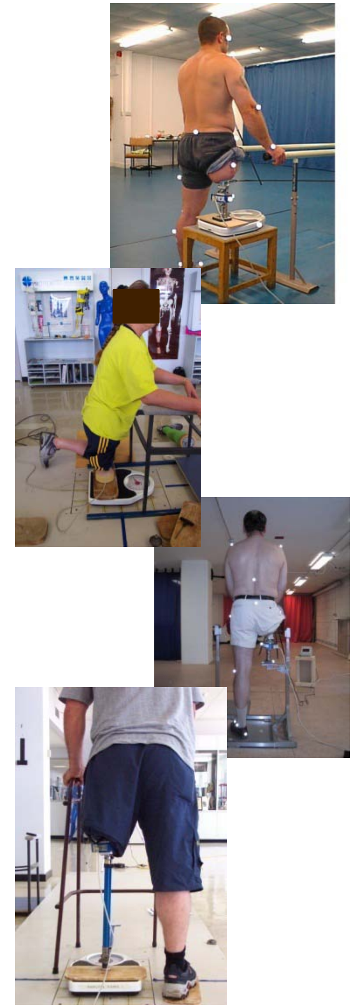
Months post-op

Rehab

6

Static



Frossard *et al.* Apparatus for monitoring load bearing rehabilitation exercises of a transfemoral amputee fitted with an osseointegrated implant: a proof-of-concept study. 2010. Gait and Posture. 31. p 223-228. doi:10.1016/j.gaitpost.2009.10.010

# Measure and results

Months post-op

Rehab

6 Static

9 **Dynamic**

Cycle

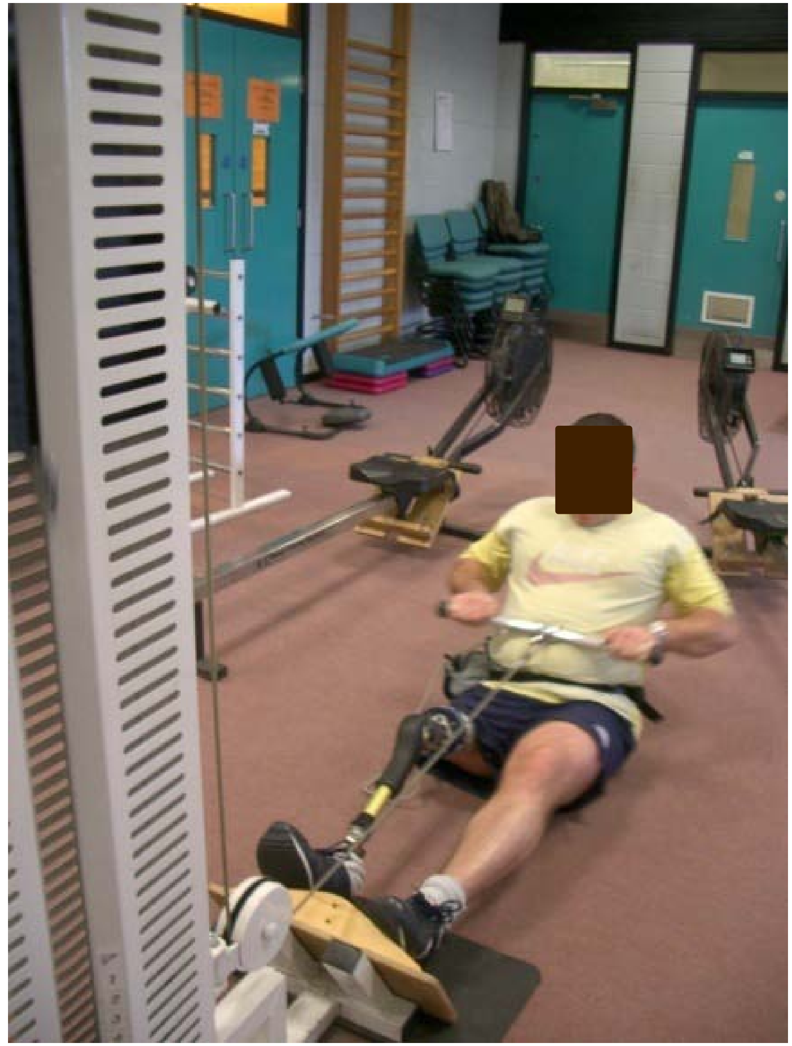
# Measure and results

Months post-op

Rehab

| | |
|---|---|
| 6 | Static |
| 9 | Dynamic |

Gym - Rowing



# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

Gym – Adduction / Abduction

# Measure and results

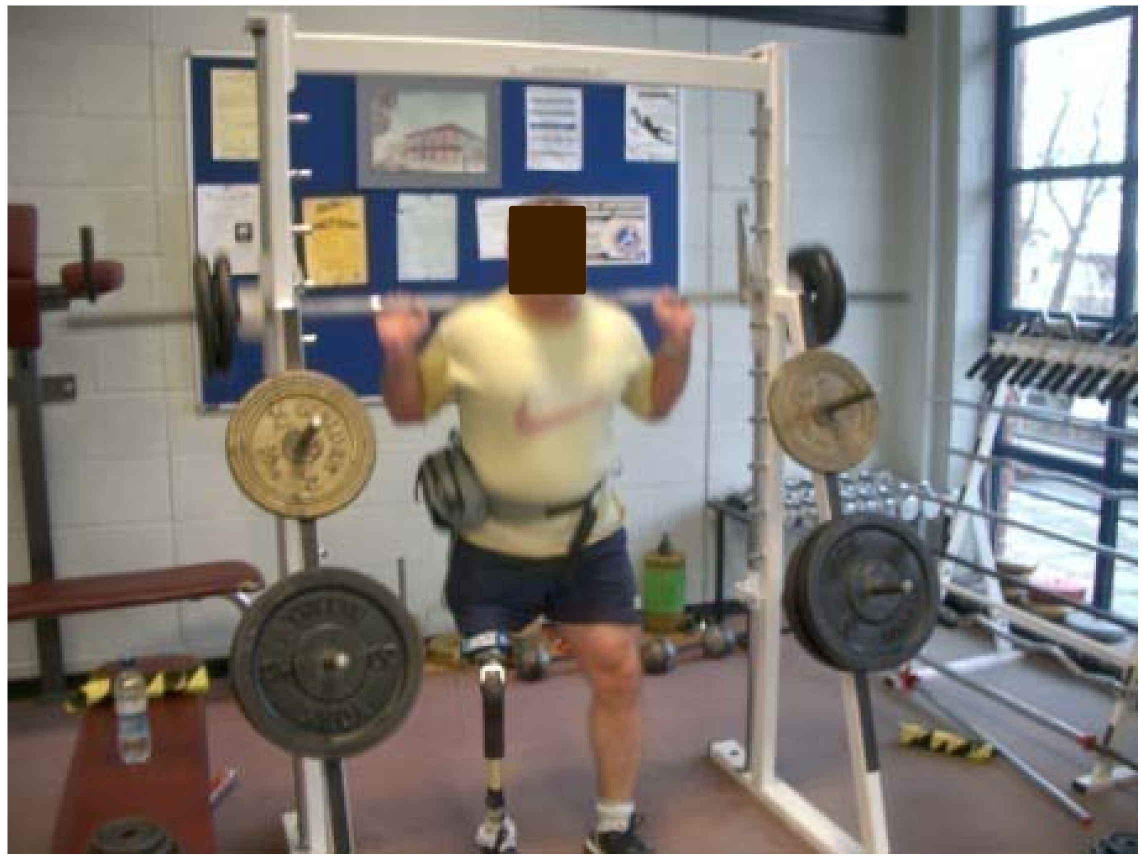
Months post-op

Rehab

6 Static

9 Dynamic

Gym – Flexion / Extension

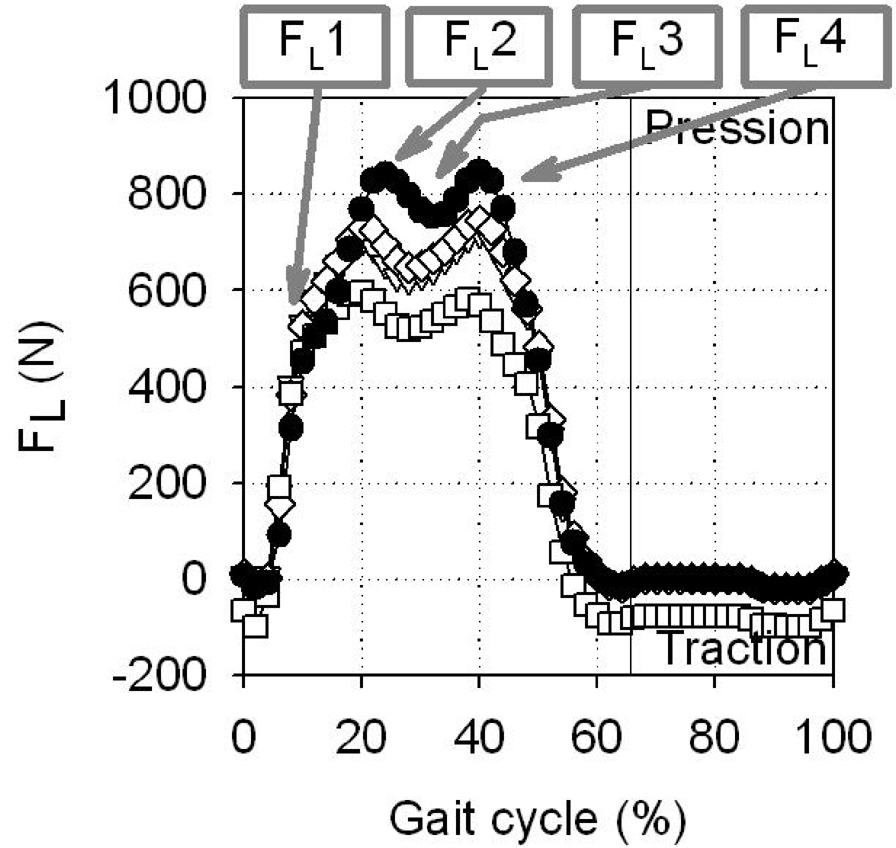


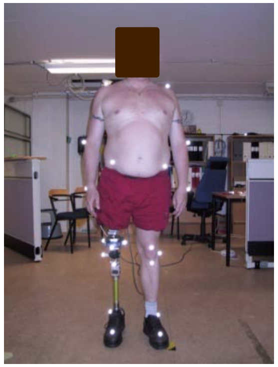
# Measure and results

Months post-op

Rehab

- 6 Static
- 9 Dynamic
- 12 Aids



Frossard *et al.* Load-relief of walking aids on osseointegrated fixation: Instrument for evidence-based practice. 2009. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 17 (1). p 9-14.

# Measure and results

Months post-op

Rehab

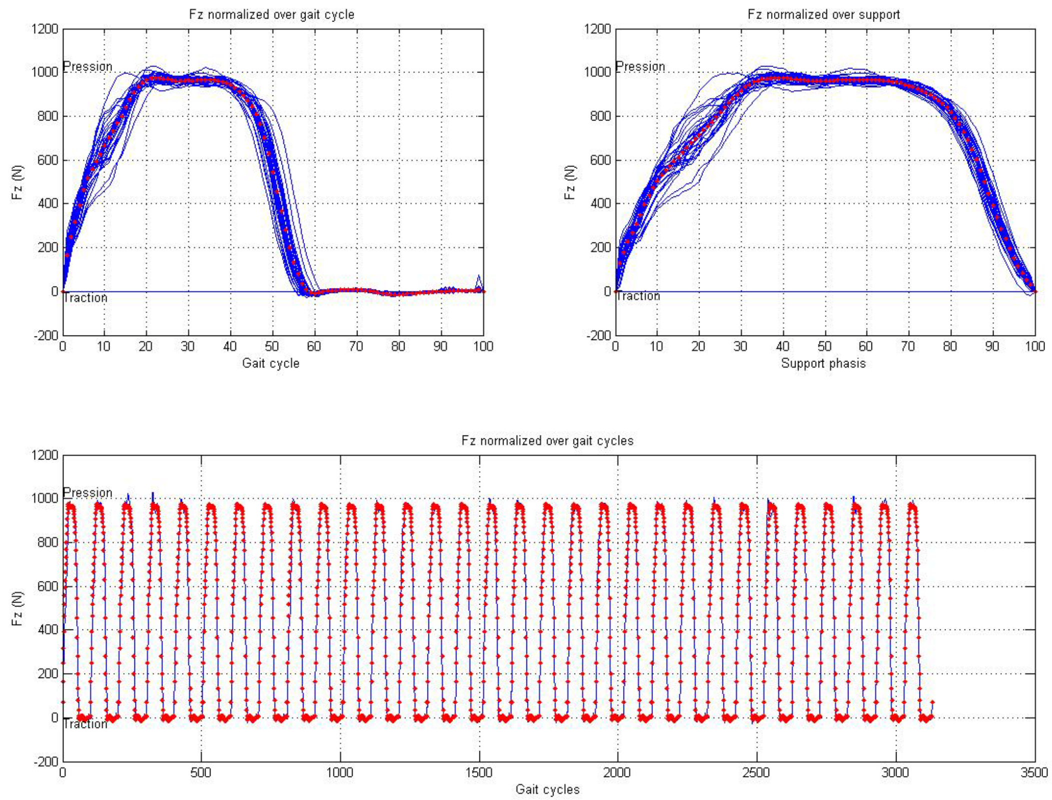
- 6 — Static
- 9 — Dynamic
- 12 — Aids

ADL

- 18 — Standard

**Walking in straight line – Parameters**

Patterns




Lee *et al*. Magnitude and variability of loading on the osseointegrated fixation of transfemoral amputees during walking. 2007. Medical Engineering and Physics. 30. p 825-833. DOI:10.1016/j.medengphy.2007.09.003

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

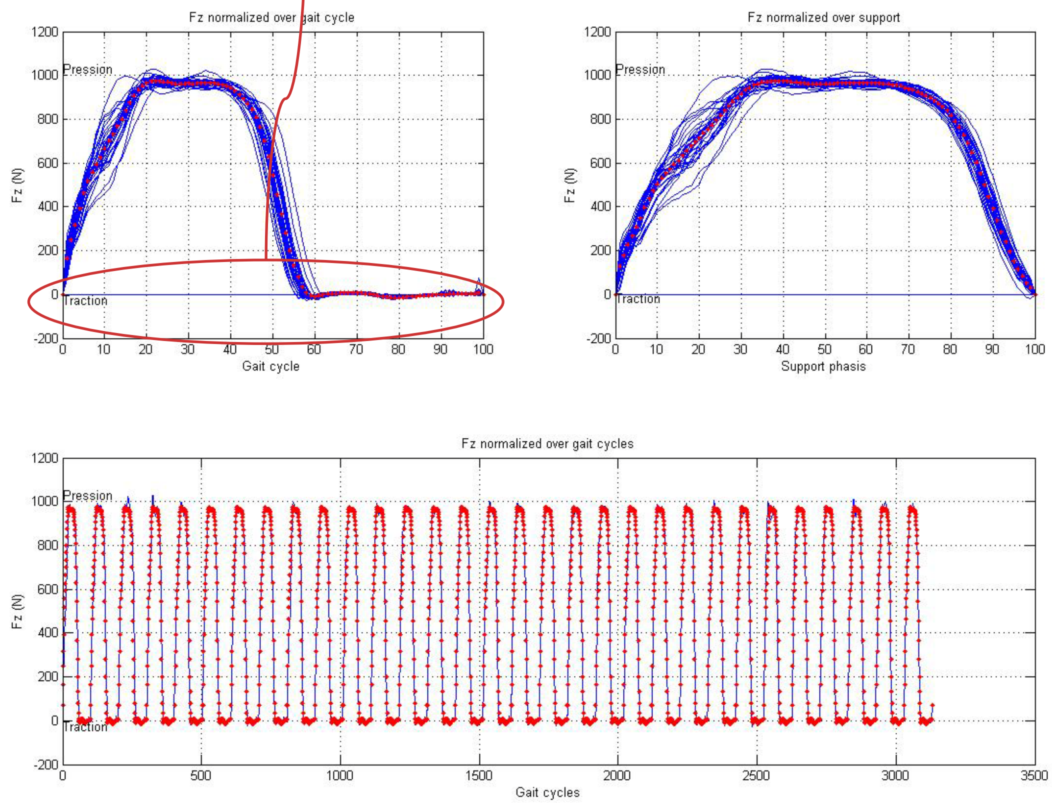
ADL

18 Standard

**Walking in straight line – Parameters**

**Patterns**

**Temporal variables**

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# Measure and results

Months post-op

Rehab

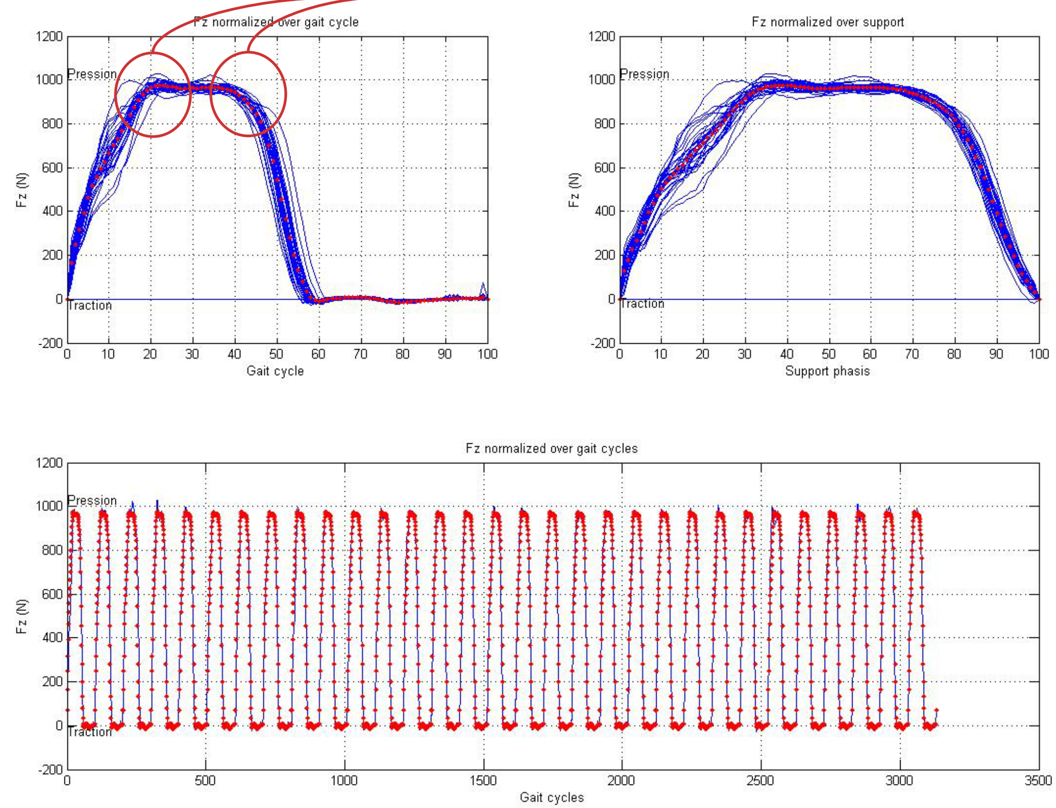
- 6 — Static
- 9 — Dynamic
- 12 — Aids

ADL

- **18 — Standard**

**Walking in straight line – Parameters**

Patterns | Temporal variables | Local extrema

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# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

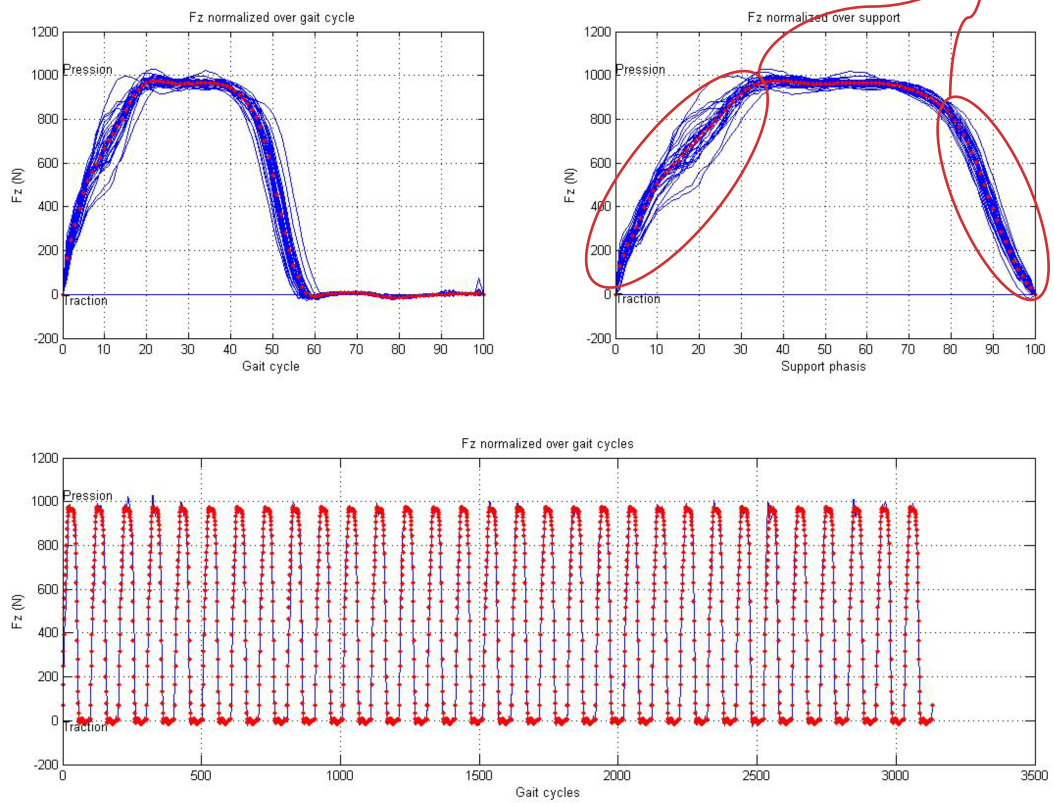
12 Aids

ADL

18 **Standard**

**Walking in straight line – Parameters**

**Patterns** | **Temporal variables** | **Local extrema** | **Loading rate**

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# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

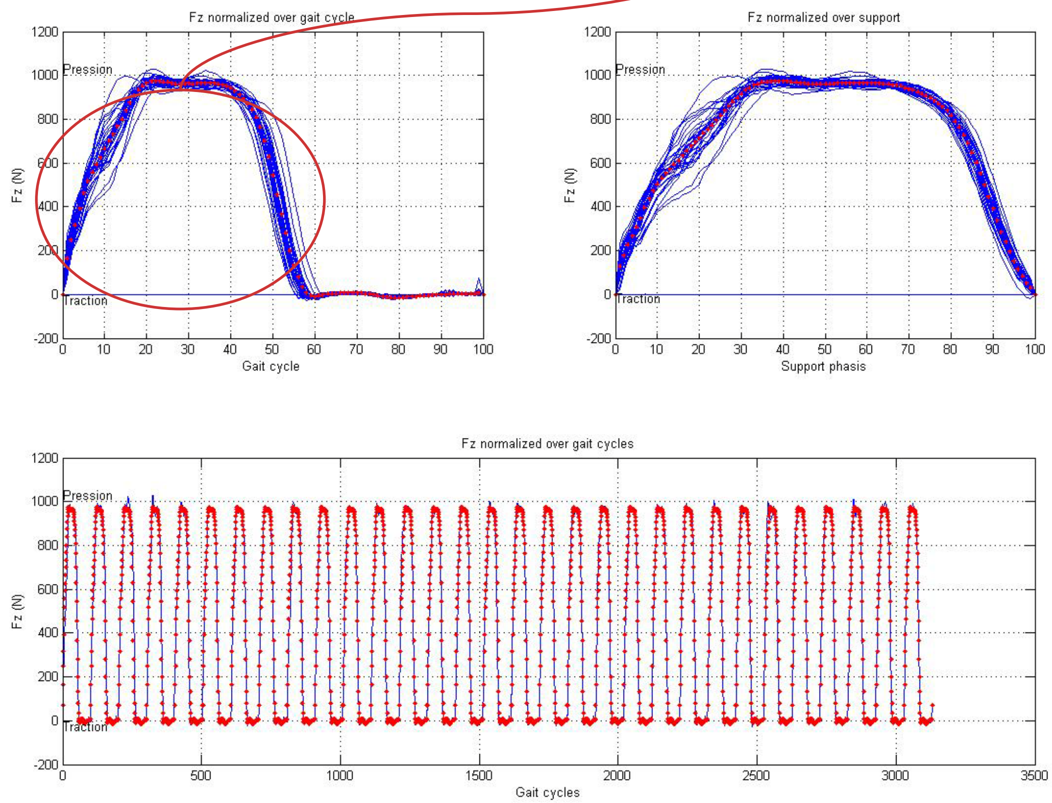
12 Aids

ADL

18 **Standard**

**Walking in straight line – Parameters**

| Patterns | Temporal variables | Local extrema | Impulse | Loading rate |
|---|---|---|---|---|



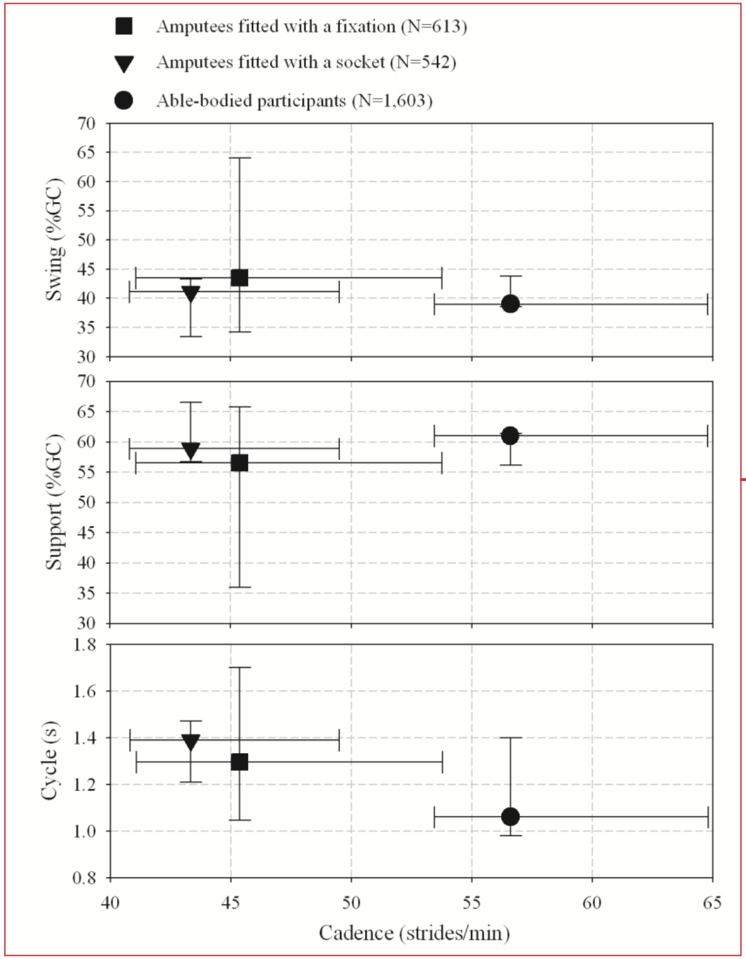

Lee *et al*. Magnitude and variability of loading on the osseointegrated fixation of transfemoral amputees during walking. 2007. Medical Engineering and Physics. 30. p 825-833. DOI:10.1016/j.medengphy.2007.09.003

# Measure and results

**Months post-op**

- Rehab
  - 6 — Static
  - 9 — Dynamic
  - 12 — Aids
- ADL
  - 18 — Standard

**Walking in straight line – Temporal variables**




**Top of transfemoral amputees fitted with sockets**

**Bottom of able-bodies**

Frossard *et al.* Functional outcome of transfemoral amputees fitted with an osseointegrated fixation: temporal gait characteristics. 2010. Journal of Prosthetics and Orthotics. 22 (1). p 11-20. DOI: 10.1097/JPO.0b013e3181ccc53d

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

ADL

18 Standard

**Walking in straight line – Variability - Force**

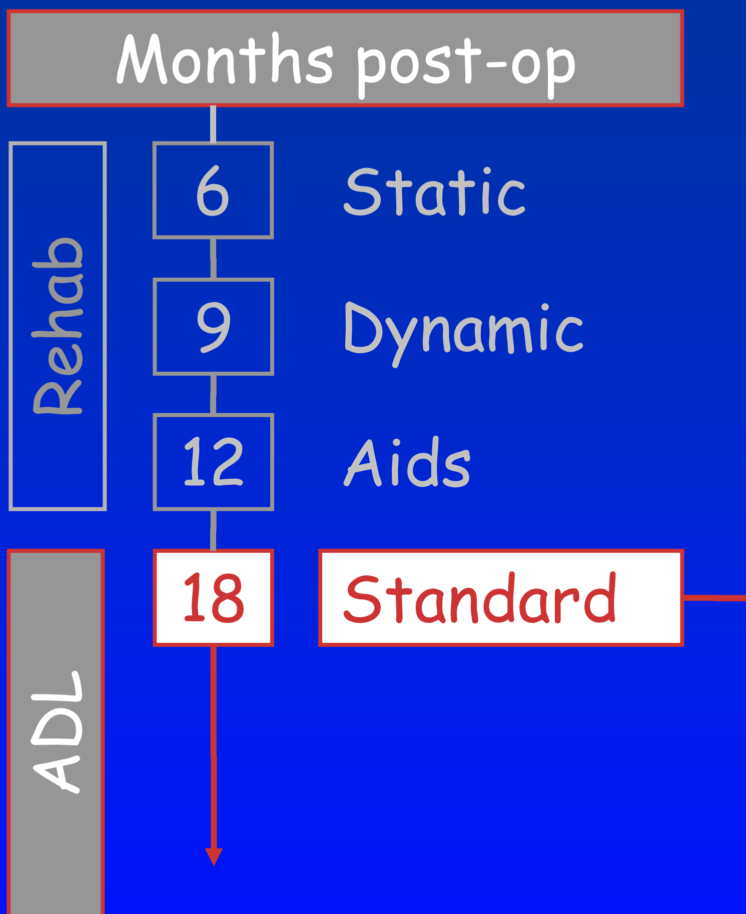
| | $F_{AP1}$ Mean | $F_{AP1}$ COV | $F_{AP2}$ Mean | $F_{AP2}$ COV | $F_{ML}$ Mean | $F_{ML}$ COV | $F_{L1}$ Mean | $F_{L1}$ COV | $F_{L2}$ Mean | $F_{L2}$ COV |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (in %SP) | | | | | | | | | | |
| Step-to-step variability | | | | | | | | | | |
| Subject 1 | 30.80 | 0.061 | 82.10 | 0.024 | 33.20 | 0.056 | 36.70 | 0.067 | 69.80 | 0.039 |
| Subject 2 | 13.40 | 0.310 | 83.10 | 0.021 | 72.00 | 0.025 | 35.60 | 0.187 | 72.20 | 0.027 |
| Subject 3 | 17.60 | 0.100 | 84.70 | 0.015 | 93.20 | 0.033 | 24.70 | 0.129 | 69.60 | 0.051 |
| Subject 4 | 17.30 | 0.134 | 74.90 | 0.025 | 74.60 | 0.030 | 31.30 | 0.160 | 69.30 | 0.032 |
| Subject 5 | 21.30 | 0.160 | 88.90 | 0.052 | 70.50 | 0.026 | 25.80 | 0.148 | 69.70 | 0.022 |
| Subject 6 | 18.40 | 0.138 | 80.20 | 0.022 | 79.60 | 0.027 | 35.50 | 0.103 | 68.40 | 0.047 |
| Subject 7 | 18.40 | 0.163 | 80.90 | 0.075 | 73.60 | 0.072 | 24.60 | 0.163 | 76.00 | 0.071 |
| Subject 8 | 16.80 | 0.123 | 79.30 | 0.020 | 72.00 | 0.030 | 36.70 | 0.055 | 69.70 | 0.028 |
| Subject 9 | 19.50 | 0.119 | 85.50 | 0.018 | 78.20 | 0.017 | 24.50 | 0.135 | 67.70 | 0.042 |
| Subject 10 | 17.60 | 0.095 | 82.30 | 0.027 | 72.00 | 0.054 | 42.20 | 0.068 | 68.90 | 0.030 |
| Subject 11 | 13.90 | 0.127 | 80.10 | 0.018 | 76.70 | 0.020 | 38.10 | 0.060 | 74.10 | 0.065 |
| Subject 12 | 8.90 | 0.174 | 76.80 | 0.039 | 67.80 | 0.130 | 41.20 | 0.128 | 68.80 | 0.082 |
| Subject-to-subject variability | | | | | | | | | | |
| Mean | 17.80 | 0.142 | 81.57 | 0.030 | 71.95 | 0.043 | 33.08 | 0.117 | 70.35 | 0.045 |
| S.D. | 5.22 | 0.062 | 3.80 | 0.018 | 13.82 | 0.032 | 6.64 | 0.045 | 2.48 | 0.019 |
| COV | 0.293 | 0.434 | 0.047 | 0.594 | 0.192 | 0.737 | 0.201 | 0.388 | 0.035 | 0.430 |
| Maximum | 30.80 | 0.310 | 88.90 | 0.075 | 93.20 | 0.130 | 42.20 | 0.187 | 76.00 | 0.082 |
| Minimum | 8.90 | 0.061 | 74.90 | 0.015 | 33.20 | 0.017 | 24.50 | 0.055 | 67.70 | 0.022 |
| Range | 21.90 | 0.249 | 14.00 | 0.060 | 60.00 | 0.113 | 17.70 | 0.132 | 8.30 | 0.060 |
| Magnitude (in %BW) | | | | | | | | | | |
| Step-to-step variability | | | | | | | | | | |
| Subject 1 | −5.07 | 0.108 | 10.80 | 0.096 | 10.80 | 0.070 | 105.00 | 0.018 | 97.20 | 0.023 |
| Subject 2 | −9.82 | 0.128 | 14.50 | 0.043 | 14.10 | 0.056 | 91.80 | 0.040 | 87.90 | 0.025 |
| Subject 3 | −13.20 | 0.016 | 21.70 | 0.018 | 7.36 | 0.071 | 80.70 | 0.034 | 83.40 | 0.017 |
| Subject 4 | −5.78 | 0.107 | 14.60 | 0.048 | 8.42 | 0.046 | 87.00 | 0.038 | 94.40 | 0.016 |
| Subject 5 | −15.40 | 0.132 | 10.20 | 0.074 | 11.60 | 0.049 | 88.50 | 0.038 | 102.00 | 0.022 |
| Subject 6 | −4.22 | 0.141 | 3.22 | 0.100 | 23.60 | 0.112 | 96.50 | 0.032 | 93.70 | 0.024 |
| Subject 7 | −11.10 | 0.068 | 15.90 | 0.038 | 19.20 | 0.045 | 97.30 | 0.036 | 99.60 | 0.018 |
| Subject 8 | −5.07 | 0.170 | 13.20 | 0.040 | 11.10 | 0.036 | 83.20 | 0.027 | 86.90 | 0.025 |
| Subject 9 | −7.46 | 0.085 | 11.50 | 0.061 | 11.40 | 0.092 | 79.10 | 0.046 | 72.20 | 0.036 |
| Subject 10 | −7.41 | 0.101 | 15.20 | 0.030 | 12.40 | 0.117 | 85.20 | 0.033 | 84.30 | 0.024 |
| Subject 11 | −5.46 | 0.119 | 21.50 | 0.020 | 15.30 | 0.068 | 89.60 | 0.029 | 81.40 | 0.048 |
| Subject 12 | −4.90 | 0.306 | 16.20 | 0.048 | 5.60 | 0.101 | 87.90 | 0.027 | 82.40 | 0.041 |
| Subject-to-subject variability | | | | | | | | | | |
| Mean | −7.91 | 0.123 | 14.04 | 0.051 | 12.57 | 0.072 | 89.32 | 0.033 | 88.78 | 0.027 |
| S.D. | 3.64 | 0.069 | 4.99 | 0.027 | 5.01 | 0.028 | 7.44 | 0.007 | 8.75 | 0.010 |
| COV | 0.460 | 0.563 | 0.355 | 0.523 | 0.398 | 0.384 | 0.083 | 0.221 | 0.099 | 0.374 |
| Maximum | −4.22 | 0.306 | 1.31 | 2.306 | 3.31 | 4.306 | 5.31 | 6.306 | 7.31 | 8.306 |
| Minimum | −15.40 | 0.016 | 3.22 | 0.018 | 5.63 | 0.036 | 79.06 | 0.018 | 72.20 | 0.018 |
| Range | 11.18 | 0.290 | 1.91 | 2.288 | 2.32 | 4.270 | 73.75 | 6.288 | 64.89 | 8.288 |

Low

High

Lee *et al.* Magnitude and variability of loading on the osseointegrated fixation of transfemoral amputees during walking. 2007. Medical Engineering and Physics. 30. p 825-833. DOI:10.1016/j.medengphy.2007.09.003

# Measure and results




**Walking in straight line – Variability – Impulse**

| | $I_{AP}$ (s) | | $I_{ML}$ (s) | | $I_L$ (s) | |
|---|---|---|---|---|---|---|
| | Mean | COV | Mean | COV | Mean | COV |
| **Step-to-step variability** | | | | | | |
| Subject 1 | 0.123 | 0.050 | 0.088 | 0.071 | 0.532 | 0.065 |
| Subject 2 | 0.085 | 0.034 | 0.035 | 0.087 | 0.464 | 0.044 |
| Subject 3 | 0.164 | 0.035 | 0.048 | 0.056 | 0.486 | 0.034 |
| Subject 4 | 0.175 | 0.044 | 0.056 | 0.064 | 0.514 | 0.041 |
| Subject 5 | 0.087 | 0.065 | 0.036 | 0.092 | 0.455 | 0.045 |
| Subject 6 | 0.068 | 0.055 | 0.147 | 0.170 | 0.581 | 0.048 |
| Subject 7 | 0.168 | 0.077 | 0.073 | 0.067 | 0.523 | 0.056 |
| Subject 8 | 0.117 | 0.069 | 0.074 | 0.063 | 0.408 | 0.067 |
| Subject 9 | 0.082 | 0.034 | 0.145 | 0.048 | 0.423 | 0.052 |
| Subject 10 | 0.101 | 0.042 | 0.129 | 0.045 | 0.441 | 0.027 |
| Subject 11 | 0.190 | 0.086 | 0.068 | 0.090 | 0.538 | 0.074 |
| Subject 12 | 0.191 | 0.101 | 0.015 | 0.140 | 0.450 | 0.081 |
| **Subject-to-subject variability** | | | | | | |
| Mean | 0.129 | 0.058 | 0.076 | 0.083 | 0.484 | 0.053 |
| S.D. | 0.046 | 0.022 | 0.043 | 0.038 | 0.054 | 0.016 |
| COV | 0.355 | 0.383 | 0.573 | 0.454 | 0.111 | 0.309 |
| Maximum | 0.191 | 0.101 | 0.147 | 0.170 | 0.581 | 0.081 |
| Minimum | 0.068 | 0.034 | 0.015 | 0.045 | 0.408 | 0.027 |
| Range | 0.123 | 0.067 | 0.132 | 0.125 | 0.178 | 0.054 |

Low

High

Lee *et al.* Magnitude and variability of loading on the osseointegrated fixation of transfemoral amputees during walking. 2007. Medical Engineering and Physics. 30. p 825-833. DOI:10.1016/j.medengphy.2007.09.003

# Measure and results

Months post-op

Rehab

6 Static

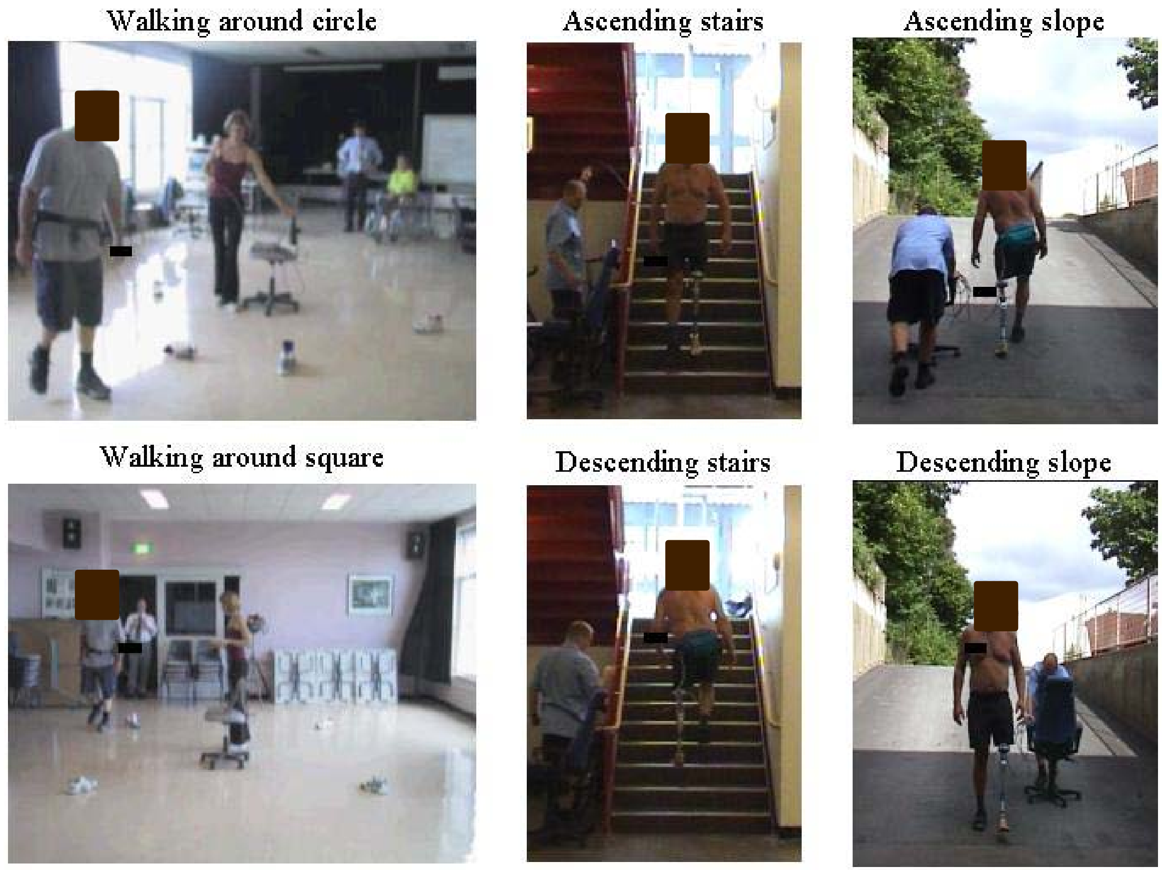
9 Dynamic

12 Aids

ADL

18 Standard

**Activities of daily living**




Lee *et al.* Kinetics of transfemoral amputees fitted with osseointegrated fixation performing common activities of daily living. 2007. Clinical Biomechanics. 22 (6). p 665-673

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

ADL

18 Standard

**Activities of daily living – Local extrema**

| | Walking | DownSlope | Upslope | DownStairs | Upstairs | Circle |
|---|---|---|---|---|---|---|
| **$F_{AP-}$ (N)** | -74 (36) | -93 (44) | -53 (34) | -137 (98) | - | -69 (29) |
| **$F_{AP+}$ (N)** | 101 (19) | 87 (29) | 90 (25) | - | 74 (20) | 84 (27) |
| **$F_{ML+}$ (N)** | 89 (35) | 79 (22) | 93 (39) | 53 (14) | 76 (30) | 93 (34) |
| **$F_{L1}$ (N)** | 671 (139) | 699 (149) | 697 (153) | 587 (157) | 769 (171) | 706 (165) |
| **$F_{L2}$ (N)** | 675 (138) | 660 (146) | 704 (144) | 649 (112) | 715 (170) | 703 (148) |
| **$M_{AP+}$ (Nm)** | 21 (10) | 25 (9) | 22 (8) | 18 (8) | 19 (8) | 27 (9) |
| **$M_{ML+}$ (Nm)** | 9 (10) | - | 17 (12) | - | 10 (14) | 11 (11) |
| **$M_{ML-}$ (Nm)** | -20 (9) | -30 (20) | -20 (9) | - | - | -18 (6) |
| **$M_{L+}$ (Nm)** | 3.7 (1.2) | 5.3 (2.7) | 3.2 (1.7) | 5.3 (3.6) | 3.0 (1.1) | 3.8 (1.7) |
| **$M_{L-}$ (Nm)** | 5.0 (2.0) | -3.8 (1.3) | -6.3 (2.5) | -3.5 (1.0) | -3.7 (1.2) | -5.4 (1.2) |

Lee *et al.* Kinetics of transfemoral amputees fitted with osseointegrated fixation performing common activities of daily living. 2007. Clinical Biomechanics. 22 (6). p 665-673

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

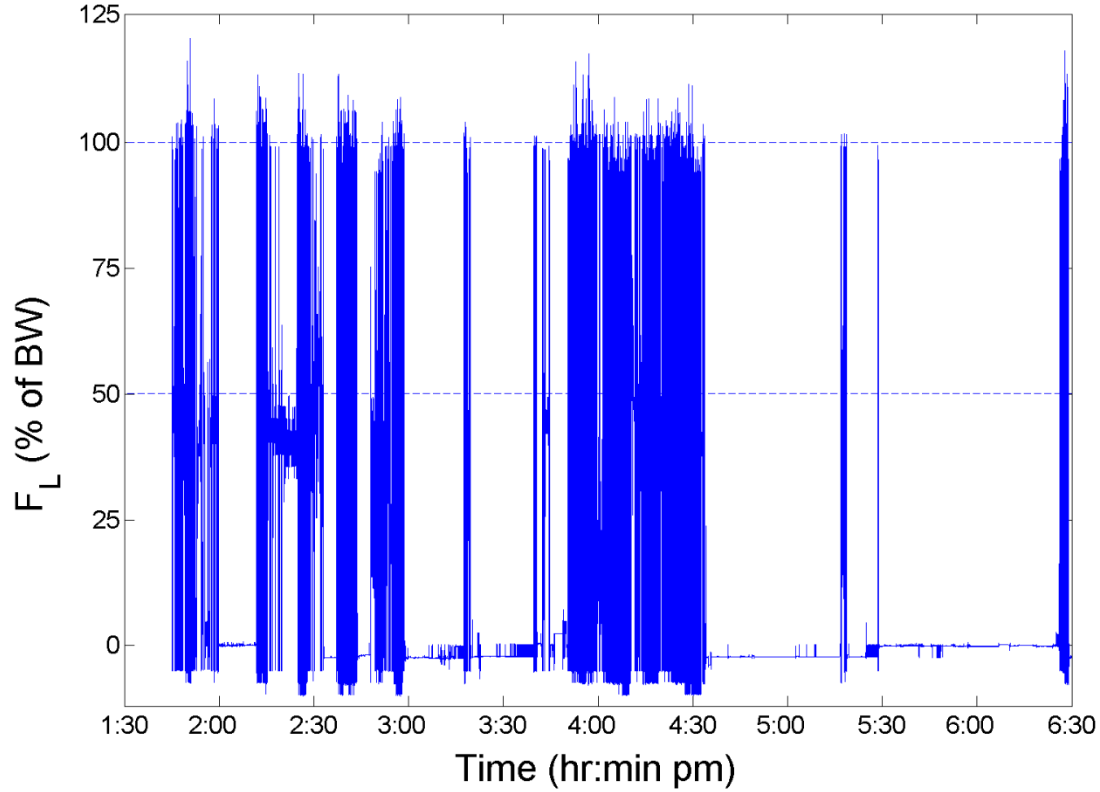
12 Aids

ADL

18 Standard

Real world

Activities of daily living – Overall analysis




Frossard *et al.* Daily activities of a transfemoral amputee fitted with osseointegrated fixation: continuous recording of the loading for an evidence-based practice. 2006. Kinesitherapie Revue. 6 (56-57). p 53-62

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

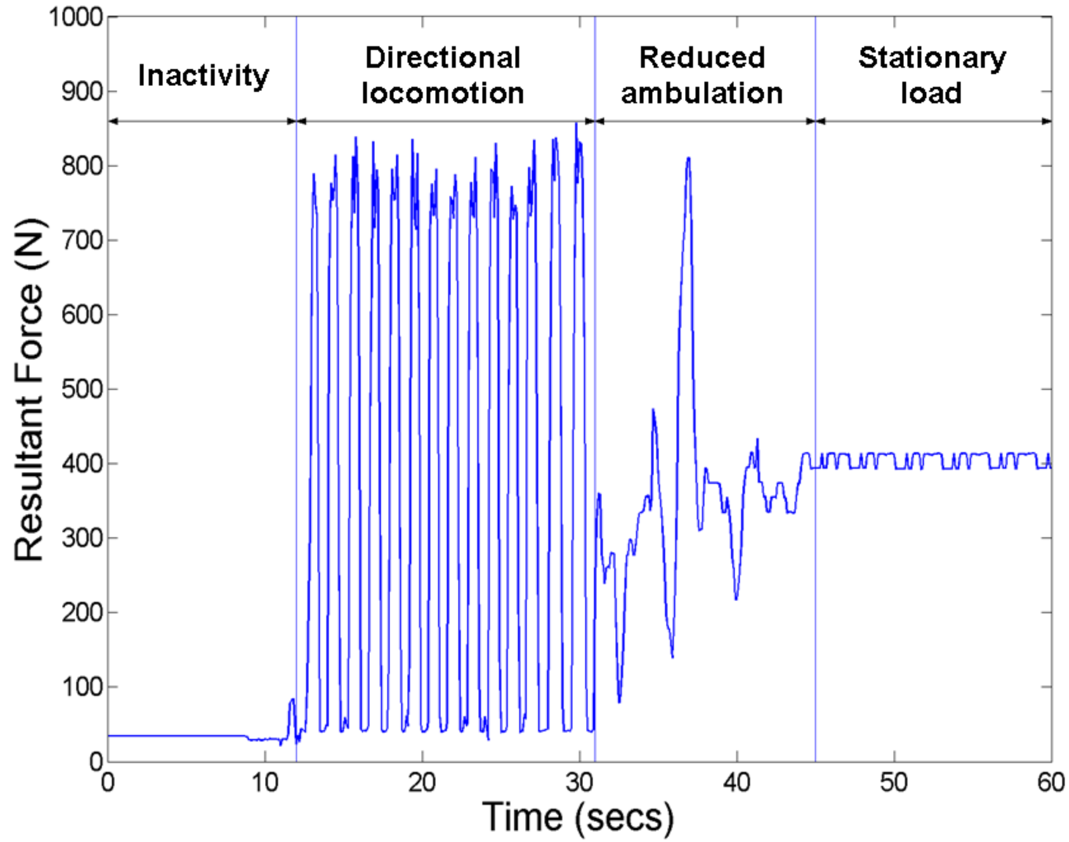
12 Aids

ADL

18 Standard

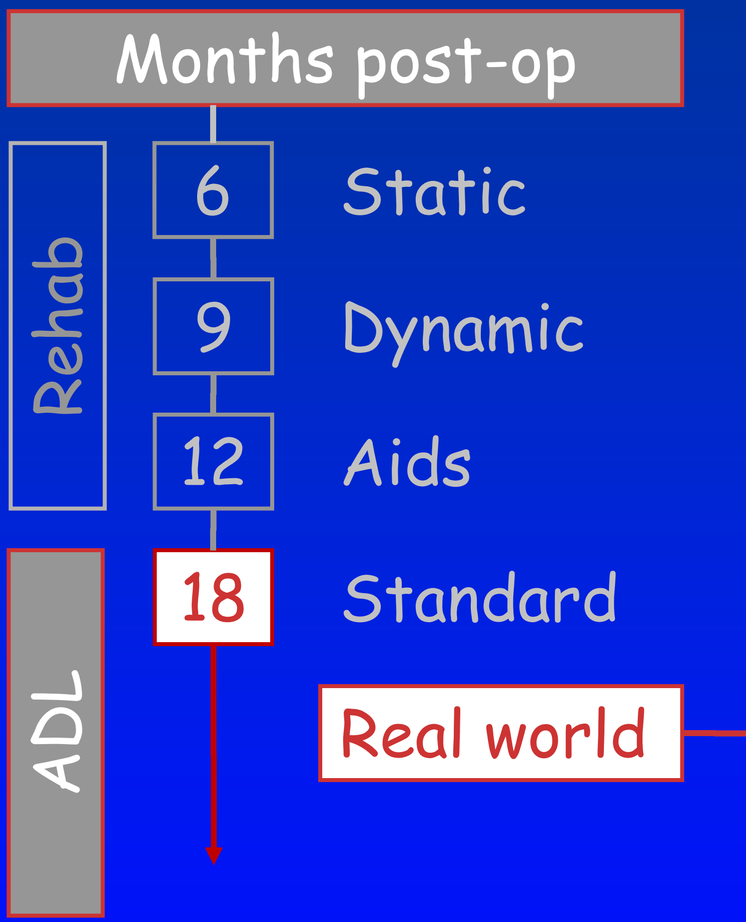
Real world

**Activities of daily living – Categorization**




Frossard *et al.* Daily activities of a transfemoral amputee fitted with osseointegrated fixation: continuous recording of the loading for an evidence-based practice. 2006. Kinesitherapie Revue. 6 (56-57). p 53-62

# Measure and results

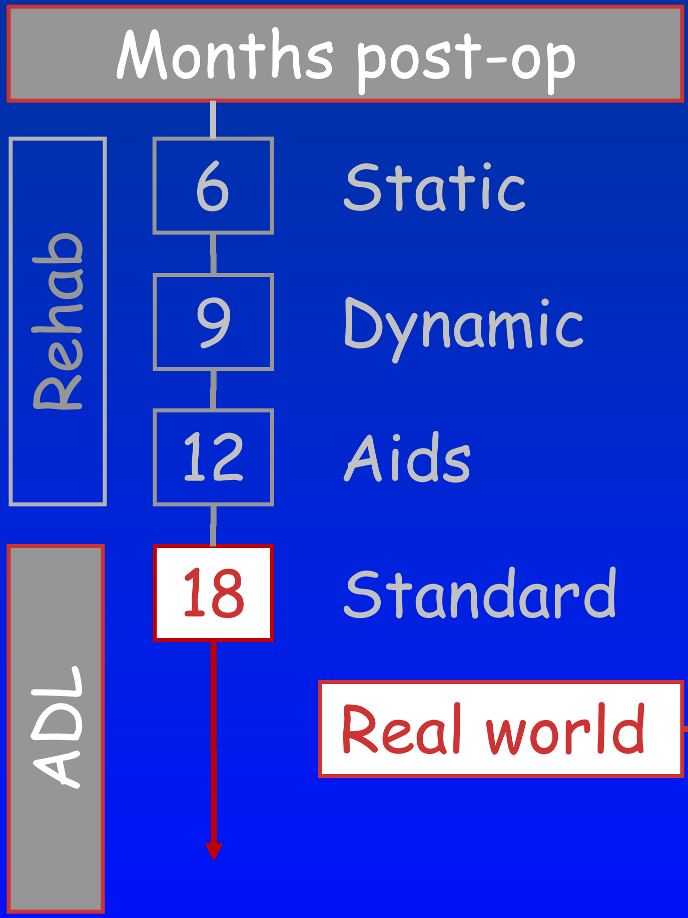



**Activities of daily living – Categorization – Occurrence and duration of activities**

| | | Periods of activity | | | | |
|---|---|---|---|---|---|---|
| | | Periods of ambulation | | | | |
| | | Directional locomotion | Localised locomotion | Stationary loading | Inactivity | Total |
| **Occurrence** | **(#)** | 67 | 51 | 33 | 21 | 172 |
| | **(%)** | 39 | 30 | 19 | 12 | 100 |
| **Duration** | **(hrs)** | 0.89 | 0.66 | 0.21 | 3.10 | 4.87 |
| | **(%)** | 18 | 14 | 4 | 64 | 100 |

Frossard *et al.* Categorisation of activities of daily living of lower limb amputees during short term use of a portable kinetic recording system: a preliminary study. Submitted to Journal of Prosthetics and Orthotics.

# Measure and results

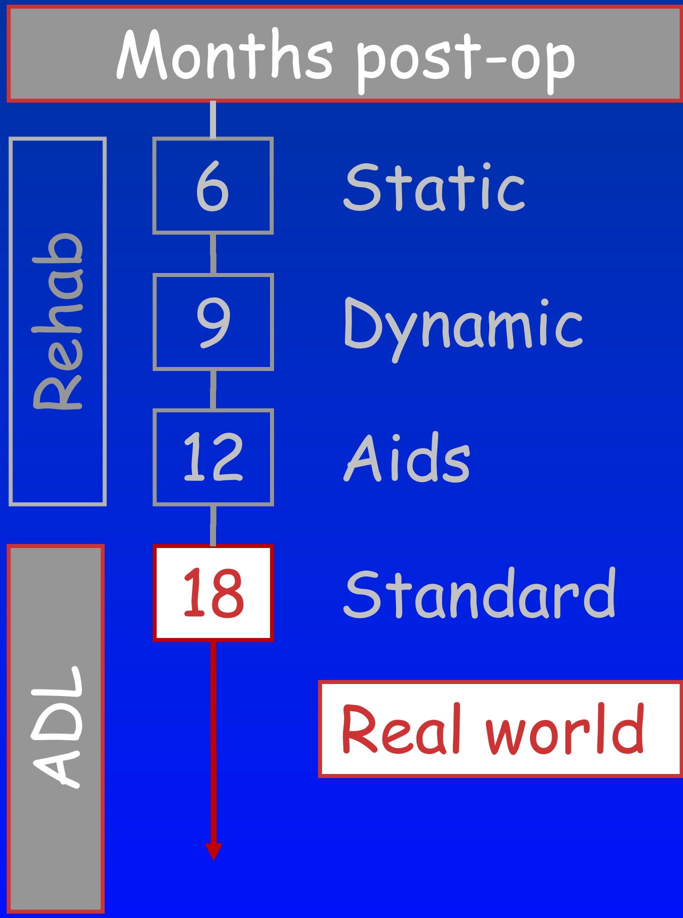



**Activities of daily living – Categorization – Descriptive analysis of load**

| | Periods of activity | | | |
|---|---|---|---|---|
| | Periods of ambulation | | | |
| | Directional locomotion | Localised locomotion | Stationary loading | Inactivity |
| **Forces (N)** | | | | |
| **Antero-posterior axis** | | | | |
| Median | 315.68 | -3.00 | 11.38 | -12.44 |
| Minimum | -181.30 | -142.22 | -107.85 | -102.26 |
| Maximum | 157.36 | 123.52 | 67.60 | 106.84 |
| **Medio-lateral axis** | | | | |
| Median | -40.65 | -34.47 | -28.19 | -5.19 |
| Minimum | -170.27 | -154.38 | -102.78 | -51.20 |
| Maximum | 25.63 | 19.13 | 16.88 | 40.41 |
| **Long axis** | | | | |
| Median | 295.73 | 335.03 | 335.75 | -17.71 |
| Minimum | -83.67 | -61.31 | -64.67 | -63.69 |
| Maximum | 1005.41 | 883.97 | 825.90 | 588.20 |
| **Moments (N.m)** | | | | |
| **Antero-posterior axis** | | | | |
| Median | -8.25 | -6.42 | -4.52 | -0.55 |
| Minimum | -32.25 | -98.76 | -24.55 | -19.34 |
| Maximum | 15.35 | 13.00 | 11.77 | 4.89 |
| **Medio-lateral axis** | | | | |
| Median | 8.54 | 5.94 | 3.77 | 0.02 |
| Minimum | -9.88 | -10.07 | -4.87 | -7.75 |
| Maximum | 50.83 | 60.18 | 30.25 | 20.56 |
| **Long axis** | | | | |
| Median | -0.79 | -1.11 | -0.13 | 1.13 |
| Minimum | -13.32 | -7.24 | -5.65 | -16.64 |
| Maximum | 11.77 | 8.42 | 7.94 | 17.94 |

Frossard *et al.* Categorisation of activities of daily living of lower limb amputees during short term use of a portable kinetic recording system: a preliminary study. Submitted to Journal of Prosthetics and Orthotics.

# Measure and results




**Activities of daily living – Categorization – Impulse**

| Impulse (kN.s) | Periods of activity | | | | |
|---|---|---|---|---|---|
| | Periods of ambulation | | | | |
| | Directional locomotion | Localised locomotion | Stationary loading | Inactivity | Total |
| Antero-posterior | 9 | 11 | 12 | 6 | 17 |
| Medio-lateral | 162 | 89 | 80 | 20 | 351 |
| Long | 1,069 | 745 | 107 | 227 | 1,935 |
| Resultant | 1,214 | 767 | 268 | 230 | 2,479 |

Frossard *et al.* Categorisation of activities of daily living of lower limb amputees during short term use of a portable kinetic recording system: a preliminary study. Submitted to Journal of Prosthetics and Orthotics.

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

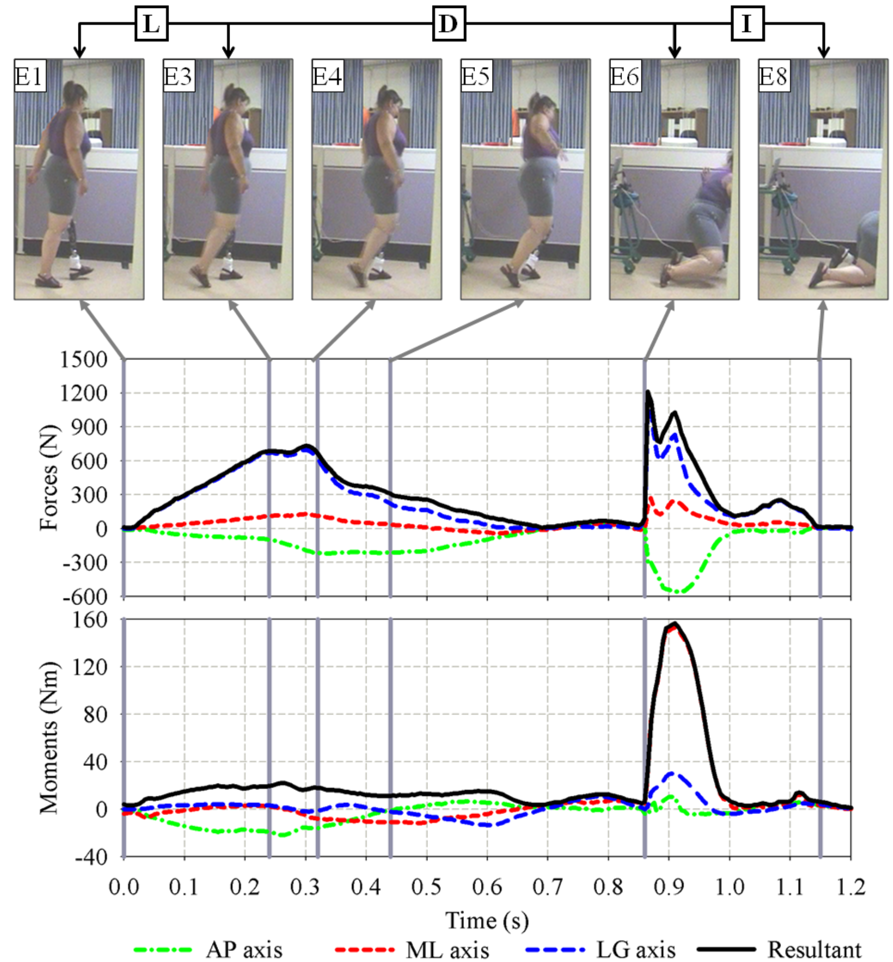
ADL

18 Standard

Real world

Fall

Meso analysis – Loading, descent, impact and recovery




Frossard *et al.* Load on osseointegrated fixation of transfemoral amputee during a fall: loading, descent, impact and recovery analysis. 2010. Prosthetics and Orthotics International. 34(1): 85–97. DOI: 10.3109/03093640903585024

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

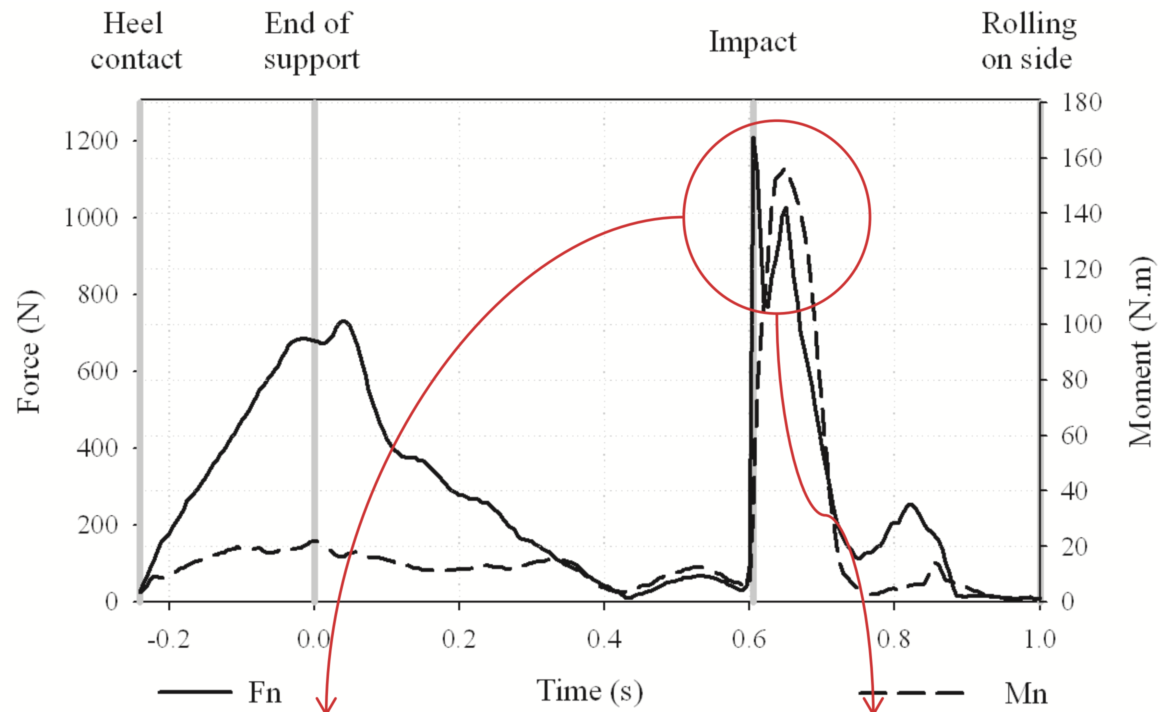
ADL

18 Standard

Real world

Fall

**Micro analysis - Impact**




**$F_{AP}$ = 62 %BW**
**$F_{ML}$ = 29 %BW**
**$F_{LG}$ = 132 %BW**

**$M_{AP}$ = 22 N.m**
**$M_{ML}$ = 153 N.m**
**$M_{LG}$ = 30 N.m**

Frossard *et al.* Fall of a transfemoral amputee fitted with osseointegrated fixation: loading impact on residuum. 2009. Gait and Posture. 30 (2). p S151-S152. DOI:10.1016/j.gaitpost.2009.08.227

# Measure and results

Months post-op

Rehab

- 6 — Static
- 9 — Dynamic
- 12 — Aids
- 18 — Standard

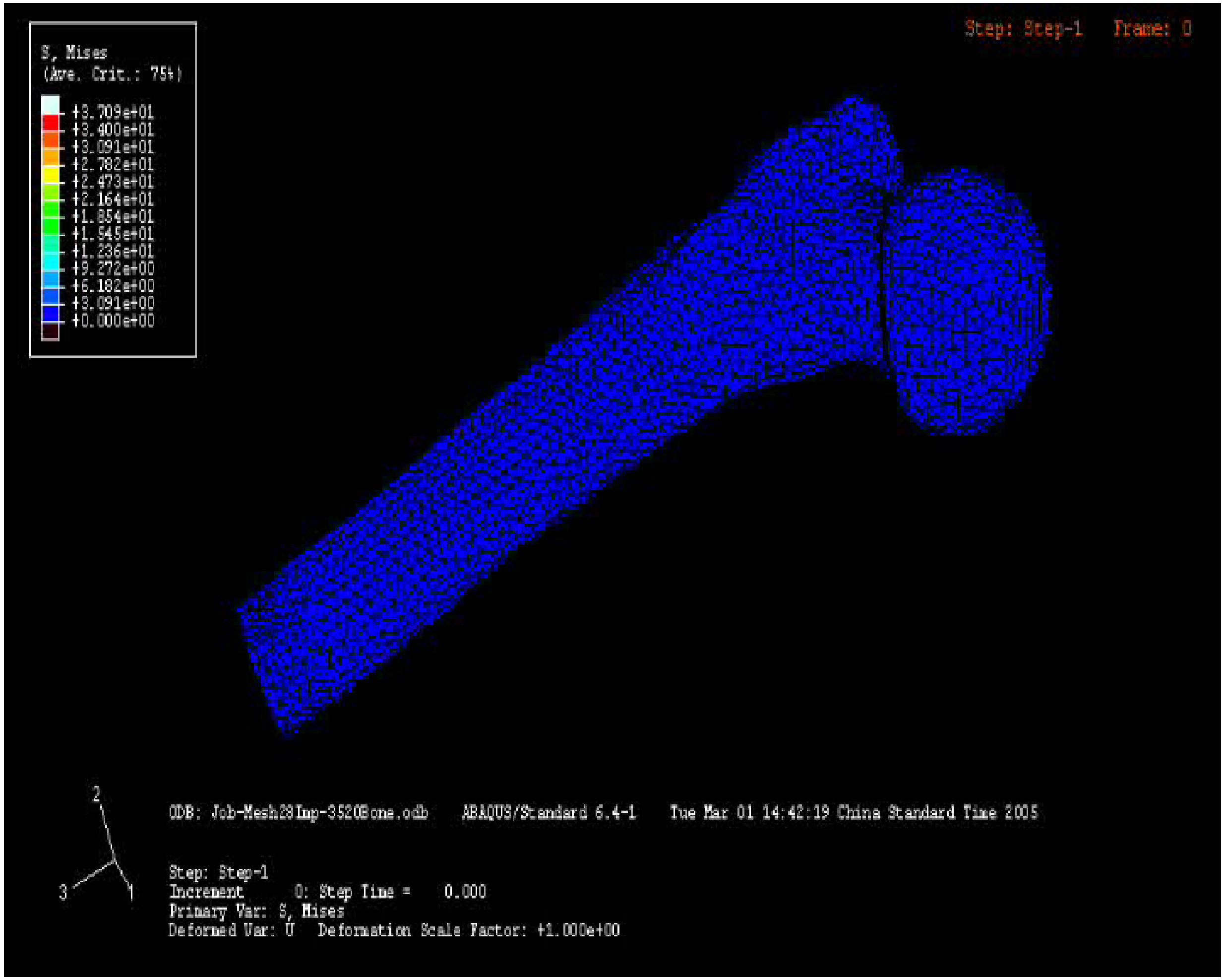
ADL

- Real world
- Fall

Other

- FE

**Risk of failure**



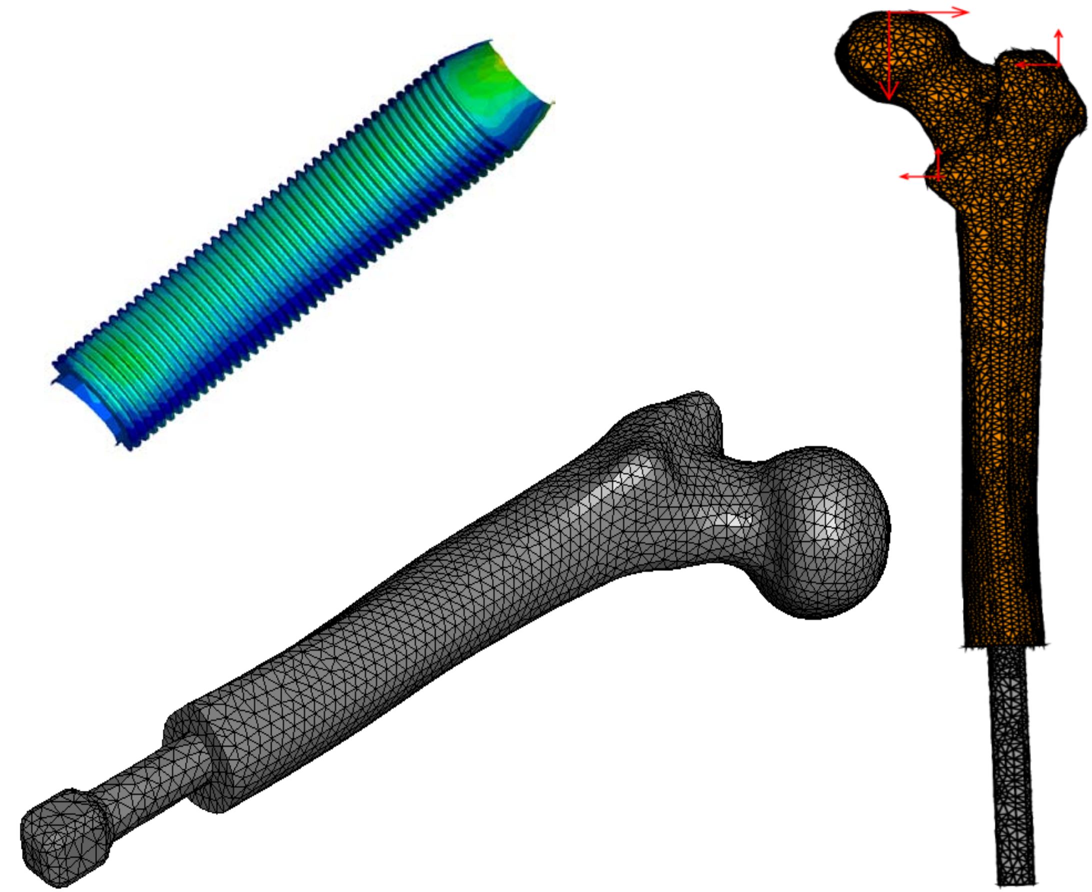

Helgason *et al.* Risk of failure during gait for direct skeletal attachment of a femoral prosthesis: A finite element study. 2009. Medical Engineering and Physics. 31. p 595–600. doi:10.1016/j.medengphy.2008.11.015

# Measure and results

**Months post-op**

| | | |
|---|---|---|
| Rehab | 6 | Static |
| | 9 | Dynamic |
| | 12 | Aids |
| ADL | 18 | Standard |
| | | Real world |
| | | Fall |
| Other | | FE |

**Stress analysis of bone – implant interface**



Lee *et al*. FE stress analysis of the interface between the bone and an osseointegrated implant for amputees– implications to refine the rehabilitation program. 2008. Clinical Biomechanics. 23 (10). p 1243-1250

# Measure and results

Months post-op

Rehab

6 Static

9 Dynamic

12 Aids

ADL

18 Standard

Real world

Fall

Other

FE

**Modelisation of tightening torque**

## Evaluating the Mechanical Behaviour of two Ossoeintegrated Transfemoral Implant Systems using 3D Digital Image Correlation when Loaded in Bending

M. Thompson[1], R. Branemark[2], D. Backman[3], C.K. Mechefske[1]

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2. Centre of Orthopaedic Osseointegration, Sahlgrenska University Hospital, Göteborg, SWEDEN
3. Institute for Aerospace Research, National Research Council, Ottawa, CANADA

Queen's UNIVERSITY

### SUMMARY

Digital image correlation was used to evaluate the static loading response of two osseointegrated transfemoral implant systems to investigate the implications of raising the tightening torque (applied during implantation) beyond the current manufacturer's specified tightening torque of 12Nm. Results suggest increased torque may increase assembly strength in response to loading.

### INTRODUCTION

Osseointegrated transfemoral implants are used to provide prosthetic solutions to individuals that cannot be accommodated by socket-based devices. Currently, a hex connection mates the implant and abutment with a tightened retention bolt used to achieve proper clamping of the three parts. A new design proposes a Morse taper connection between the implant and abutment with a retention bolt used in the same way. This design has been successful in oral implants of a similar construction [1, 2]. Preliminary work comparing the transfemoral components suggests both assemblies may achieve increased strength when tightened beyond the manufacturer's specified tightening torque (12Nm) [3]. This study evaluates the mechanical response during static loading to investigate the implications of tightening to the current tightening torque (12Nm) as well as an increased specification (25Nm). The systems were loaded in bending, using loads representative of those observed during activities of daily living [4].

### METHODS

- Twelve bolts were coupled with implant/abutment components
  - -six bolts using a hex connection
  - -six using the Morse Taper connection (Figure 1)
- Each design type was divided into two groups
  - -three samples tightened to 12Nm
  - -three samples tightened to 25Nm.
- External loads were applied to the assembly in a cantilever orientation to observe its response to bending
  - -nine loading conditions were observed, all loading was applied by calibrated weights 40-120lbs
- Digital image correlation was used to measure the strain response for each loading condition.
- All results were evaluated visually

**Figure 1**: Two osseointegrated transfemoral connection methods; hex-based (top) and Morse taper (bottom)

**Figure 2**: Experimental set-up - digital image correlation

### RESULTS

Digital image correlation showed deformation over the entire field of view, identifying critical locations within the part during a series of loading conditions. Figure 3 provides a representative image of all nine test conditions that were observed, (1) natural, unloaded, (2) torqued, unloaded (3-7) torqued and loaded incrementally from 40-120lbf, (8) torqued, unloaded, and untorqued, unloaded. Red/orange represents tension, yellow/green represents compression. It can be seen that the highest tensile stresses were observed at the implant-abutment interface (left side of the field of view). Figure 4 illustrates the typical loading during activities of daily living. Increased tightening torque decreases the observed tensile stress concentrations. Figure 5 shows the highest loading condition, 120lb applied load. This condition represents the peak loading observed during a fall. This condition produced the most active response to loading for all of the four test groups. These images illustrate that increased tightening torque substantially decreases the tensile strain concentrations and increases the compressive strains experienced by the samples. It was also seen that increased torque decreased the peak strain magnitude and increased torque retention.

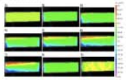


**Figure 3**: Representative output from the digital image correlation loading conditions

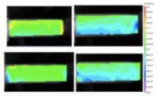


**Figure 4**: The digital image correlation results during 40lbf applied load. Hex, 12Nm (top left) Hex, 25Nm (top right), Taper, 12Nm (bottom left), Taper, 25Nm (bottom right)

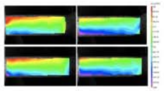


**Figure 5**: The digital image correlation results during 120lbf applied load. Hex, 12Nm (top left) Hex, 25Nm (top right), Taper, 12Nm (bottom left), Taper, 25Nm (bottom right)

### CONCLUSIONS

Preliminary evidence suggests that both the hex-based and Morse taper assemblies exhibit improved performance when tightened to a level beyond the current specified tightening torque of 12 Nm. Increased tightening torque increased the preload force within the assembly by raising the compression between bolted components. This led to increased torque retention, decreased peak tensile strain values and a more gradual, primarily compressive distribution of strains throughout the assembly. These results were achieved by evaluating the behaviour and material response in the presence of a tightening torque established as approximately 75% of the ultimate tensile strength of the material. Additional testing must be performed to increase the statistical power of the ultimate strength criterion for these assemblies.

### REFERENCES

1. Norton, M.R., 1997. An in vitro evaluation of the strength of an internal conical interface compared to a butt joint interface in implant design. Clin Oral Implants Res. 290-298.
2. Merz, B.R., Hunenbart, S., Belser, U.C., 2000. Mechanics of the implant-abutment connection: an 8-degree taper compared to a butt joint connection. Int J Oral Maxillofac Implants. 15, 519-526.
3. Thompson, M.L., 2009. Mechanical analysis of osseointegrated transfemoral implant systems. (MScEng thesis, Queen's University, 2009)
4. Frossard, L.A., Stevenson, N.J., 2004. Continuous Recording of the load applied on the osseointegrated fixation system of a transfemoral amputee.
5. Trilling, J., 1988. Torque data for socket-head cap screws. Fastener Technology. 3-4.

Thompson *et al*. Evaluating the Mechanical Behaviour of two Ossoeintegrated Transfemoral Implant Systems using 3D Digital Image Correlation when Loaded in Bending. ISPO 2010

# Measure and results

Months post-op

Rehab

- 6 Static
- 9 Dynamic
- 12 Aids
- 18 Standard

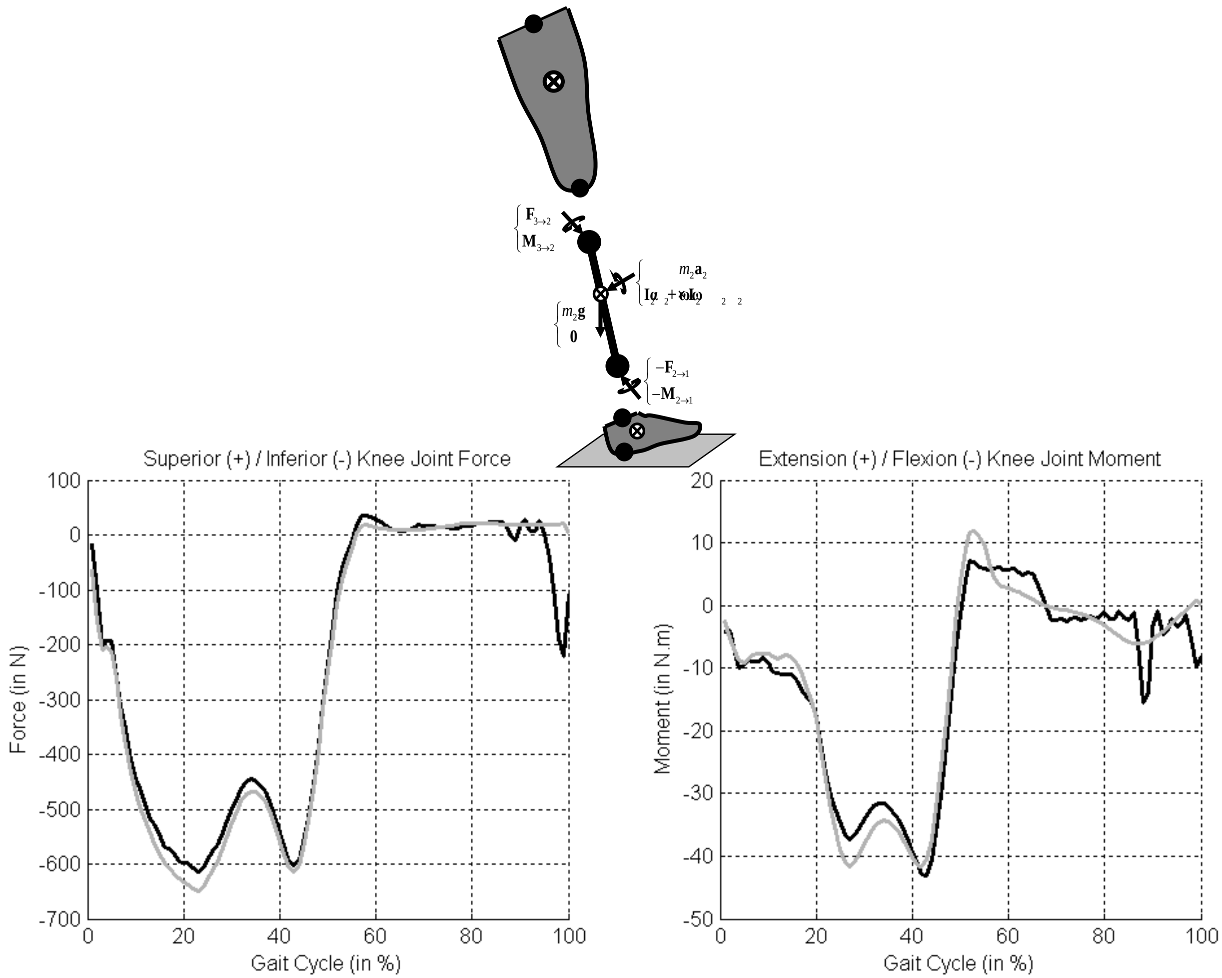
ADL

- Real world
- Fall

Other

- FE
- Validation

**Inverse dynamics - Efforts at the knee joint**




Dumas *et al.* Load during prosthetic gait: is direct measurement better than inverse dynamics? 2009. Gait and Posture. 30 (2). p S86-S87. DOI: 10.1016/j.gaitpost.2009.08.128

# Measure

Months post-op

Rehab

ADL

Other

6 Static

9 Dynamic

12 Aids

18 Standard

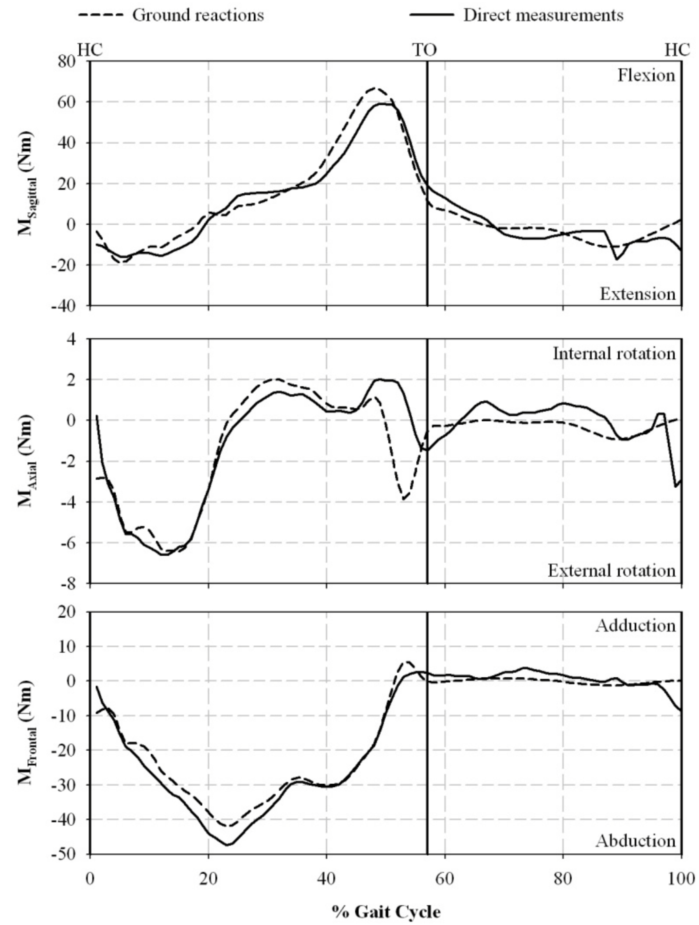
Real world

Fall

FE

Validation

Inverse dynamics - Efforts at hip joint - Moment



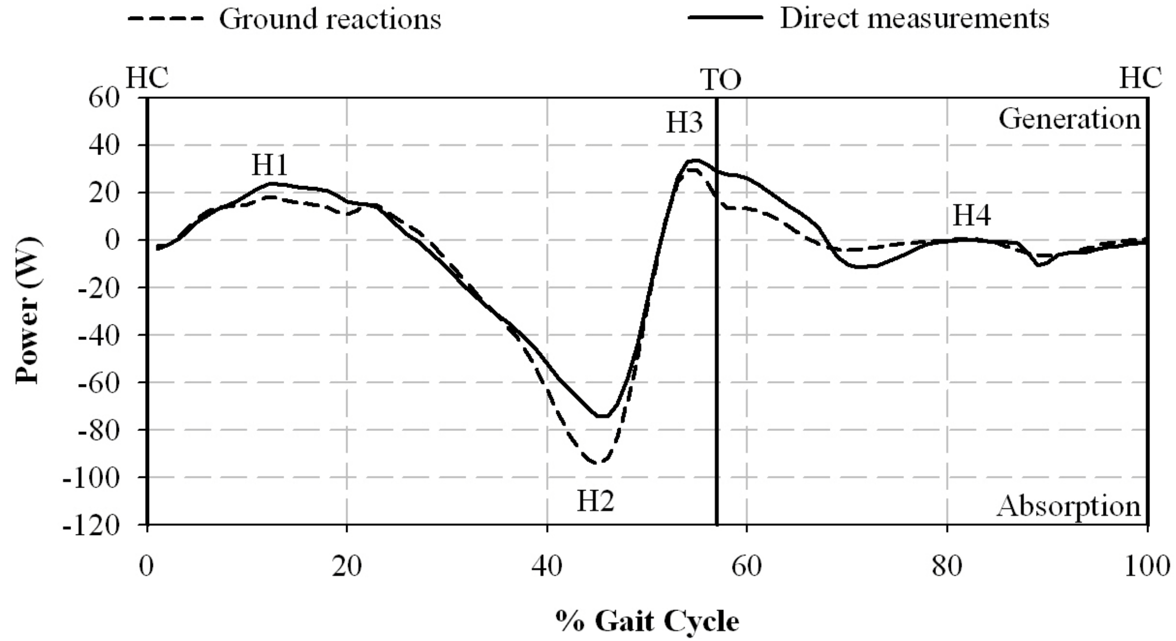

Dumas *et al.* Dynamic input to determine hip joint moments, power and work on prosthetic limb of transfemoral amputee: ground reactions vs direct measurements. Submitted Prosthetics & Orthotics International

# Measure and results

Months post-op

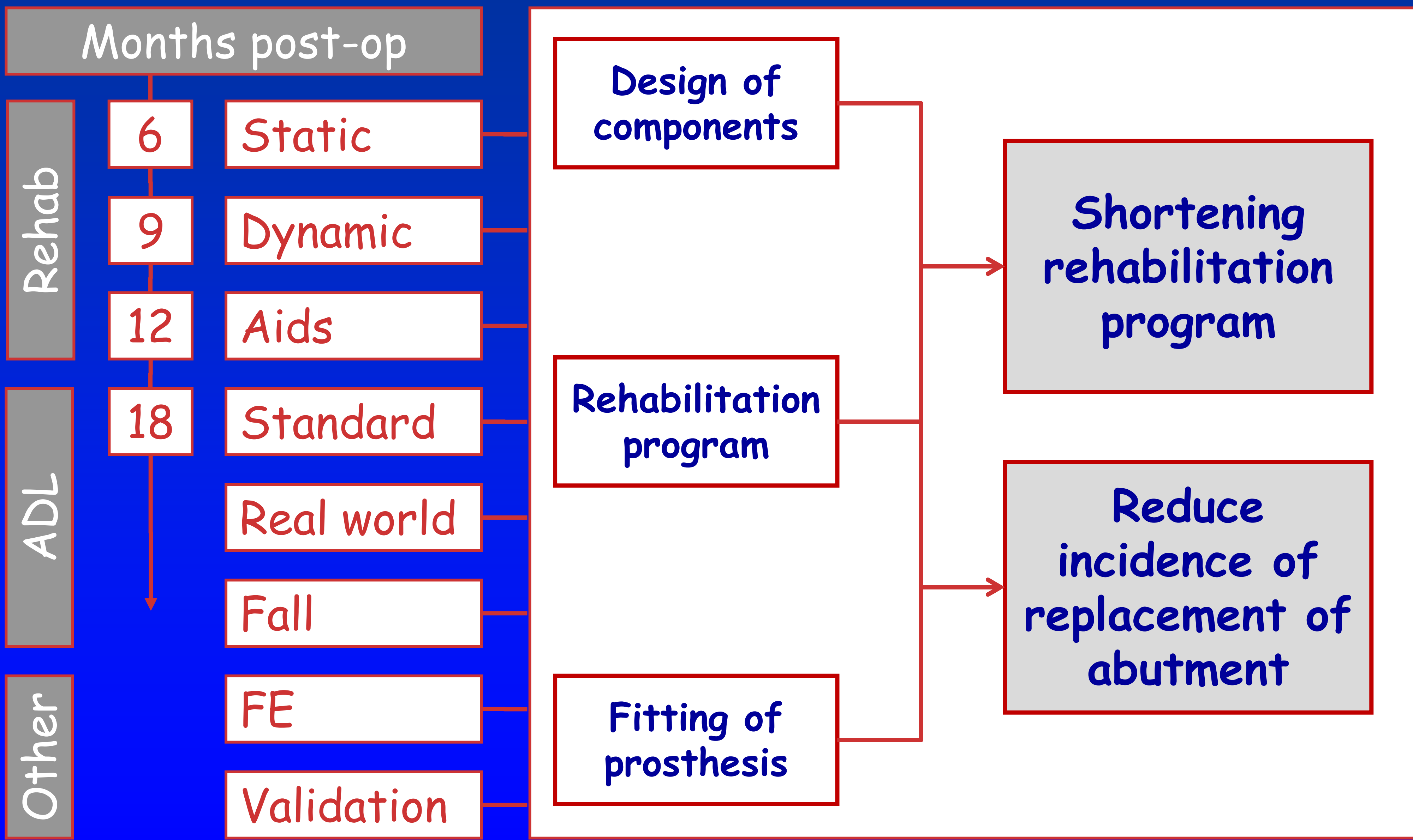
| | | |
|---|---|---|
| Rehab | 6 | Static |
| | 9 | Dynamic |
| | 12 | Aids |
| ADL | 18 | Standard |
| | | Real world |
| | | Fall |
| Other | | FE |
| | | Validation |

Inverse dynamics - Efforts at hip joint - Power




Dumas *et al.* Dynamic input to determine hip joint moments, power and work on prosthetic limb of transfemoral amputee: ground reactions vs direct measurements. Submitted Prosthetics & Orthotics International

# Overall outcomes



# Questions ?

Now !

or

Later

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# To know more!

http://www.er.uqam.ca/nobel/protamine/

# Biomechanics of transfemoral amputees fitted with osseointegrated fixation: Loading data for evidence-based practice


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02/09/2010 - Göteborg, Sweden